Distribution and Weathering of Macondo oil in Nearshore Soils, Sediments, and Tissues Collected Between Spring 2010 to Spring 2012 Based on Chemical Fingerprinting Methods

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September 3, 2015

Executive Summary

The *Deepwater Horizon* NOAA NRDA oil spill response included multiple nearshore investigations involving the collection of environmental samples between 2010 and 2012 along the coastlines of Louisiana, Mississippi, Alabama, and Florida and proximal waters within 3 nautical miles of the northern Gulf of Mexico shoreline. Nearshore samples consist of soils, sediments, solids, sheens, pom-poms, and tissues. They were chemically analyzed and forensically compared to fresh and weathered Macondo oil reference samples. The chemical composition and spatial distribution of hydrocarbon signatures help identify the natural resources that were exposed to Macondo oil as a result of the 2010 *Deepwater Horizon* oil spill. This report describes the identification of Macondo oil in 34% of the 5,605 nearshore samples as part of multiple independent sampling work plans.

Multiple technical work groups drafted sampling work plans summarized in the appendices of this report to evaluate Macondo oil impacts to a variety of human and ecological receptors. The primary investigations focused on shoreline areas, coastal wetland vegetation, submerged aquatic vegetation, nearshore areas, oysters, submerged oil, and others. Several smaller studies provided supplemental information for the research and development of analytical methods, fish kills, toxicity studies, and baseline surveys. In order to evaluate the potential impacts of the oil spill, NOAA NRDA nearshore assessment teams collected and analyzed 511 soil, 3,222 sediment, 132 solid, 1,003 pom-pom, 2 sheen, 732 tissue, and other samples. These results identified specific examples of Macondo oil impacts in the nearshore environment.

The chemical fingerprinting results demonstrate that Macondo oil traveled from the wellhead to the shorelines of Louisiana, Mississippi, Alabama and Florida. The chemical fingerprint of Macondo oil extended west to Atchafalaya Bay, Louisiana and east to Apalachicola, Florida. The highest PAH concentrations occurred in stranded oil and pom-pom samples throughout the study area. The highest overall PAH concentrations among the sediment/soil/solid samples and tissue samples occurred in Bay Jimmy, Louisiana and along the Louisiana barrier islands. The concentration of the Macondo oil generally declined during the study period, especially in areas where the oil mixed with shallow soil and sediment. The chemical fingerprint of the Macondo oil changed as a result of chemical, physical and biological weathering both during the oil's migration from the wellhead to the shoreline and after deposition along the shoreline environments. Previously-studied floating oil samples demonstrated a median PetPAH$_{27}$ depletion of 65% that increased to 94% among stranded oil samples, mostly due to evaporation (recalculated from Stout 2015a,b). After deposition, the PetPAH$_{27}$ depletion progressed to 97% due to the continued effect of evaporation augmented by microbial biodegradation. The hydrocarbon concentration statistics for all nearshore samples in Louisiana, Mississippi Alabama and Florida are compiled by sample, geographical location, depth, matrix, and sampling plan.

Introduction

The DWH drilling platform exploded on April 20, 2010 releasing 3.19 million barrels of crude oil from the Macondo well into the Gulf of Mexico (U.S. District Court, 2015). Oil was actively discharged for 87 days until the wellhead was sealed on July 15, 2010 (Crone and Tolstoy, 2010). Once released, the oil rose approximately 1,500 m (0.93 mi), covered an estimated 39,600 sq km (15,300 sq mi) of surface water, and traveled at least 77 km (48 mi) to the northern Gulf of Mexico shoreline (Environmental Response Management Application, 2015). In an attempt to minimize impact from the increasing volume and expanse of the oil, approximately 2 million gallons of dispersants (COREXIT 9500 and COREXIT 9527) were applied at the wellhead and on the oil slick (OSAT-1, 2010). Other clean-up strategies included capturing, skimming, and burning oil. Despite preventative efforts, oil reportedly first reached coastlines from Louisiana to Florida between May, 2010 and June, 2010 (NOAA 2010a; National Park Service 2010). Its inland progression continued over subsequent months.

The nearshore environment is functionally defined in this report as the supratidal (above the high tide water), intertidal (between low and high tide water), and subtidal (below the low tide water) regions. The nearshore study area generally extends inland to the stormwater reach of GOM seawater and offshore 3 miles. It encompasses habitats such as salt marshes, submerged aquatic vegetation (SAV) beds, oyster reefs, and soft mud bottoms. Combined, these habitats provide both ecological and economic value. First, the vegetation and microorganisms found within marshes and SAV beds improve the water quality of surface waters by utilizing excess nutrients for growth, ultimately removing pollutants (USEPA 2006; USEPA 2012; Neckles *et al.* 1997). Similarly, oysters form hummocks and remove particulates, plankton and nutrients from the water column (Coen *et al.* 2007). The improved water quality and dynamic habitat structure inherent to the nearshore are ideal breeding grounds for fish and other marine organisms (Ziemen 1982; Thayer *et al.* 1984). Included in the rich diversity of the nearshore environment are the eastern oyster, blue crab and blue fin tuna (Sumaila *et al.* 2012); a few of the many commercially viable species that directly enhance the regional economies. The human population also depends on the same environment to provide protection. Flooding, erosion and devastation from storms threaten coastal populations. Wetlands along the shoreline help reduce the impacts of these events by protecting the shoreline and reducing the magnitude of waves (Gedan *et al.* 2011). Due to the abovementioned significance of the nearshore environment, characterizing the extent and nature of oil introduced into these habitats resulting from the Deepwater Horizon oil spill is an important step in determining potential injury resulting from oil contamination.

Nearshore oiling impacted at least 2,113 km (1,313 mi) of northern GOM shoreline (Nixon *et al.* 2015). Shoreline cleanup assessment teams (SCAT) patrolled and documented visible oil along the accessible areas. Stranded oil was detected on 1,773 km of shoreline in the Gulf of Mexico including beaches (50.8%), marshes (44.9%), and other shorelines (4.3%) (Michel *et al.* 2013). Macondo oil residues occurred as oily emulsions, black tarballs, and stained surfaces (e.g., soil, sediment, solids, vegetation, and other objects) on the shorelines of Louisiana, Alabama, Mississippi, and Florida (Rosenbauer *et al.* 2010). Satellite images taken in the fall of 2010 showed heavy oiling along the Louisiana coast (Turner *et al.* 2014). Two dominant plant species found in Gulf of Mexico coastal marshes (*Spartina alterniflora* and *Juncus roemerianus*) show plant mortality under heavy oiling (Mishra *et al.* 2012; Lin and Mendelssohn, 2012). From May 2010 to June 2013, hydrocarbon concentrations attributed to Macondo oil were observed in coastal wetland environments (Turner *et al.* 2014). In order to gain a better understanding of impacts from an oil spill of this magnitude, a large number of samples representing both multiple locations and matrices (*e.g.* sediments, soil, and tissue) were collected to forensically confirm that the observed oil was attributable to Macondo oil.

Immediately following the spill, multiple technical working groups (TWGs) developed numerous sampling work plans (SWPs) that governed the collection of multimedia samples (soil, sediment, solid, water, tissue, and pom-poms) to investigate the potential impacts of Macondo oiling on nearshore environments[1]. Each sample was analyzed for one or more forensic testing methods. The testing methods included polycyclic aromatic hydrocarbons (PAHs), saturated hydrocarbons (SHC) or geochemical biomarkers. Laboratory results from these analyses provided "chemical fingerprinting" data appropriate for identifying the Macondo oil residues. The forensic methods and results for the nearshore water samples are discussed in Payne and Driskell (2015). The chemical fingerprinting methods and forensic classification protocol for soil, sediment, solid, tissue, and pom-pom samples are discussed in Emsbo-Mattingly (2015a). This nearshore forensic classification protocol compares field samples to fresh and weathered Macondo oil reference samples. It also recognizes changes in the Macondo oil signature associated with ambient hydrocarbon mixing. This report provides the forensic testing and classification results for each major TWG and the appendices provide the results for each sample and work plan. In addition, synoptic maps of the forensic results within each major study areas demonstrate the spatial distribution of Macondo oil in the nearshore environment.

Nearshore Overview

Six formal TWGs plus other NOAA and State groups created approximately 20 SWPs to collect and analyze samples as part of the NRDA assessment of Macondo oil impacts along the northern GOM shoreline (Table 1). The NOAA NRDA nearshore assessment teams collected and analyzed 511 soil, 3,222 sediment, 132 solid, 1,003 pom-pom, 2 sheen, 732 tissue, and other samples. These nearshore SWPs include a range of random and non-random sampling strategies focused on coastal wetlands, beaches as well as intertidal, and subtidal areas. Summaries of the sampling design and results for each major work plan are provided in Appendices 2 to 7. The initial assessments during the summer of 2010 characterized the ambient background conditions (Figure 1). Subsequent investigations in 2010 documented the nature and extent of early Macondo oil impacts in the nearshore environment. The extensive length of shoreline with Macondo oil impacts required many TWGs to establish sampling areas in representative habitats for ongoing monitoring of long-term effects and natural recovery between 2011 and 2013. Several TWGs created supplemental plans to address potential environmental risks not covered by the existing plans. The spatial and temporal trends for each workplan are summarized in the following sections with supporting information in the associated appendices. The forensic results for individual samples are provided in the nearshore report database (Attachment).

Larger scale observations are evident when viewed synoptically across multiple TWGs and SWPs. The frequency (sum Nearshore Forensic Classification Codes A, B, and C) and purity (Nearshore Forensic Classification Codes A and B versus C) of Macondo oil residues are generally elevated in the coastal wetland vegetation samples and decline with distance from the intertidal area as evidenced among the submerged oil and oyster samples (Table 2). The frequency and purity of the Macondo oil was generally higher in Louisiana followed by Alabama, Mississippi, and Florida (Table 3). The median and maximum alkylated PAH ($PetPAH_{27}$) concentrations in solid (soils, sediments, and solids) samples with Macondo oil (n=1,462) was generally higher in Louisiana followed by Florida, Alabama, and Mississippi (Table 4). The sum of the alkylated PAHs ($PetPAH_{27}$) is a bulk PAH measurement that is sensitive to fresh and weathered Macondo oil and useful for evaluating environmental weathering (Emsbo-Mattingly 2015a). The median and maximum $PetPAH_{27}$ concentrations in tissue samples with Macondo oil (n=20) was generally higher in Louisiana followed by Mississippi. All Alabama and Florida tissues were

[1] The field teams functionally defined soil as a particulate laden matrix collected above the tide line and sediment as particulates collected below standing water. It is recognized that these definitions reflect a measure of visual and temporal subjectivity. The tidal stage can affect the definition of the sample matrix; e.g., the field team may identify intertidal sediment as soil when collected at low tide. Additionally, many of the CWV soils were likely sediment in geological history. Hence, matrix designations reported by the field teams are maintained herein with the recognition that some degree of interchangeability exists among soil, sediment, and solid definitions.

Indeterminate (Table 5). The $PetPAH_{27}$ concentrations in pom-pom samples with Macondo oil (n=398) were more broadly distributed with maxima in Mississippi and Alabama (Table 6). Maps of the major nearshore study areas demonstrate the synoptic distribution of Macondo oil identified by the SCAT teams and forensic chemistry samples in all matrices (Figures 2 to 11).

The field sampling teams collected most of the nearshore samples in 2010 and 2011 with far fewer in 2012 (Figure 12). High frequencies of Macondo oil detections (Classification Codes A, B, and C) began in August 2010 and declined during the 2011 and 2012 sampling seasons. In part, this decline reflects the reduction in forensic chemistry testing at sites with known Macondo oil impacts. Lower detection frequencies also reflect environmental weathering of Macondo oil as evidenced by the depletion of petrogenic PAHs ($PetPAH_{27}$) relative to hopane (%$PetPAH_{27}$ Depletion; Emsbo-Mattingly 2015a). Floating oil samples exhibited a median %$PetPAH_{27}$ Depletion of 65% (Figure 13), primarily attributable to evaporation and dissolution (recalculated from Stout 2015a). The saturated hydrocarbon patterns (normal alkanes and acyclic isoprenoids) demonstrated ongoing evaporation and dissolution that increased the median %$PetPAH_{27}$ Depletion to 80% among intertidal sediments with visually evident oil staining (samples of opportunity; SOO) and 94% among stranded oil samples (recalculated from Stout 2015b). The normal PAH, normal alkane and acyclic isoprenoid hydrocarbon patterns indicate further evaporation and biodegradation among the Macondo oil impacted CWV soils (median %$PetPAH_{27}$ Depletion = 97%), but submerged sediments appeared to degrade more slowly (median %$PetPAH_{27}$ Depletion = 87%).

The environmental weathering trends among Macondo oil impacted samples from multiple investigations help construct a nearshore conceptual site model (Figure 14). Floating oil was the primary source of Macondo oil in the nearshore environment and exhibited a wide range of evaporation and dissolution. In 2010, floating oil coalesced into mats among bathymetric depressions, mixed with subtidal and intertidal sediments or was blown farther onshore, creating stranded oil.

The stranded oil samples largely appear as evaporated oil in the form of black discs, black fragments, or surface stains in the intertidal and supratidal zones. Biodegradation begins quickly when Macondo oil mixes into the ambient soil and sediment. The evaporation and biodegradation are more rapid in surficial upland environments, likely due to elevated temperatures and exposure to air. Evaporation, dissolution and biodegradation proceed more slowly in subtidal areas. Macondo oil impacts were primarily observed within 100 m of the shoreline although some occurred farther offshore between 2010 and 2012. It is expected that weathering will continue to degrade all but the most recalcitrant oil fractions; however, questions remain about the re-distribution of existing Macondo oil residues along eroding or accreting shorelines.

The forensic hydrocarbon patterns (saturates, PAHs, and geochemical biomarkers) provide ongoing diagnostic information about the source of Macondo oil that continues to appear sporadically in the nearshore environment (Figure 13). For example, the stranded oil samples that appeared on the shoreline after Tropical Storm Lee (September, 2011) and Hurricane Isaac (August, 2012) exhibited geochemical biomarker patterns that matched Macondo oil. The %$PetPAH_{27}$ depletion (median %$PetPAH_{27}$ depletion = 90% and 92%, respectively) provides evidence that the post-storm stranded oil was most likely submerged oil as opposed to redistributed upland oil, because %$PetPAH_{27}$ depletion values can only remain stable or increase over time. The presence of subtidal oil deposits are further supported by the collection of samples after 2012, which was the last year of forensic sample collection for this report. For example, samples containing Macondo oil collected in 2013 from an oyster bed and a previously unidentified oil mat exhibited median %$PetPAH_{27}$ depletion values between 90% and 91%, which are consistent with the upper range of submerged oil samples collected between 2010 and 2012. By contrast, samples containing Macondo oil collected in 2013 from CWV areas exhibited higher %$PetPAH_{27}$ depletion values (median %$PetPAH_{27}$ = 99%), which was consistent with the upper range of CWV samples collected between 2010 and 2012. Therefore, the geochemical biomarker patterns help identify lingering Macondo oil impacts, the saturated hydrocarbons help identify the environmental weathering process, and the %PetPAH$_{27}$ depletion offers lines of evidence that help determine 1) the extent to which environmental weathering continues to mineralize the Macondo oil and 2) the likelihood that it originated from upland or submerged deposits.

Pre-Oil Samples and Ambient Baseline Conditions

Field teams collected sediment samples from the nearshore environment to establish baseline conditions before the impact of Macondo oil (Table 1 and Figure 1). Of these samples, 176 are considered Pre-Oil samples and were collected between April 29 and July 15, 2010 under the following SWPs:

- FLDEP—Baseline—Early May 2010/FLDEP—Baseline—Late May 2010
- MDEQ Preassessment Early May 2010/MDEQ Preassessment Late April 2010
- Nearshore Sed&Water—Baseline—Early July 2010/Nearshore Sed&Water—Baseline—Late June 2010
- SAV—Baseline-Tier 1—2010
- Shoreline—Baseline—2010

Initially, the Pre-Oil samples were forensically analyzed without prior knowledge of their pre-oil status using the protocol in Emsbo-Mattingly (2015a). The sediment samples were assigned to Classification Code D, signifying an indeterminate match to fresh or weathered Macondo oil. The term, "Pre-Oil," was introduced after scientists used Synthetic Aperture Radar (SAR) to estimate the arrival of Macondo oil at various points throughout the nearshore study area. The SAR results helped determine that these 176 sediment samples represented the ambient hydrocarbons in the nearshore study area with a high degree of certainty that no Macondo oil was present. This finding was significant, because the absence of Classification Codes A, B, and C among the Pre-Oil samples demonstrated that the nearshore forensic classification protocol did not produce false-positive results (i.e., the identification of Macondo oil when it is not present) among the samples that contained ambient hydrocarbon patterns with potential residues of historical oil spills and natural seep discharges. The Pre-Oil samples were integrated into the forensic classification protocol when characterizing ambient hydrocarbon patterns in other samples. They also helped recognize residual biomarkers and PAHs that might otherwise obscure the chemical fingerprint of Macondo oil.

Coastal Wetland Vegetation Investigations

Coastal wetland vegetation (CWV) provides important human and ecological services. Worldwide, more than one third of the human population resides in coastal areas and coastal wetlands provide a buffer between local communities and the sea by protecting the shoreline and reducing the size of waves (Gedan *et al.* 2011). Additionally, vegetation fixes carbon, removes contaminants from the air and water, and protects birds, animals, insects and fish. All of these services decline or disappear when CWV is threatened. Loss of marsh vegetation can in turn increase erosion and compromise the habitat of many commercially viable species, potentially causing acute and chronic effects on aquatic flora and fauna as well as threatening the coastal human population (Kokaly *et al.* 2013; Gedan *et al.* 2011).

Macondo oil reached the marshes near the Mississippi River Delta and Barataria Bay within weeks of the release covering an estimated 796 km (495 mi) of Gulf Coast marshes (Ramsey *et al.* 2011; Judy *et al.* 2014). Observed deleterious effects of oiling on CWV include "reduced plant photosynthesis, transpiration, shoot height, stem density, and biomass as well as impaired growth and regrowth, and even completely mortality" (Lin and Mendelssohn 2012). While heavy oiling results in the death of all species of marsh vegetation, effects of moderate oiling are species specific. *Spartina alterniflora* and *Juncus roemerianus*, two dominant saltmarsh species, exhibited different responses to oiling. Specifically, *S. alterniflora* recovered from moderate oiling while *J. roemerianus* experienced deleterious effects (Lin and Mendelssohn, 2012). As such, impacts are variable and need to be spatially defined. Quantifying oiling along the northern GOM shoreline is an important step in characterizing the effects of intense and prolonged oiling on coastal marshes.

This report presents the chemical fingerprinting results associated with three CWV sampling work plans (SWPs) implemented between September, 2010 and June, 2011. The SWPs governed the collection of 511 soil, 660 sediment and 1 solid sample (Table 1). In total, Macondo oil was recognized in 59% of CWV samples, which represented 72% of the CWV sites sampled (Tables A2.1a and A2.1b). The remaining 41% of samples and 28% of sites exhibited no clear evidence of Macondo oil. The highest percentage of impacted samples and sites occurred in Louisiana, followed by Mississippi, and Alabama. Florida was not sampled under these SWPs. Maps showing the spatial extent of the impacted samples are provided (Figures 2-11).

The highest $PetPAH_{27}$ concentrations among the 690 soil/sediment/solid samples impacted by Macondo oil occurred in Louisiana ($PetPAH_{27}$ = 1,520,000 μg/kg dry weight), although the median PAH concentration among impacted Louisiana soil/sediments was much lower ($PetPAH_{27}$ = 641 μg/kg dry weight). PAH concentration statistics for impacted CWV soils in Mississippi and Alabama were calculated, but based upon far fewer samples (Table A2.1c). The herbaceous wetland samples trended towards higher frequencies of Macondo oil detection and higher $PetPAH_{27}$ concentrations among the edge plots in Louisiana (Tables A2.3a and A2.5a); however, this spatial gradient was generally reversed among the mangrove samples (Tables A2.3b and A2.5b). The marsh cleanup samples exhibited higher concentrations at the edge plot (Table A2.5e). The CWV samples studied herein show that depletion of $PetPAH_{27}$ reached a median of 97% due to the combined effects of continued evaporation and microbial biodegradation. A more detailed breakdown of CWV results by sampling plan, vegetation type, and zone are summarized in Appendix 2.

Nearshore Sediment and Water Sampling Results and Discussion

The Nearshore TWG developed two SWPs to assess 1) ambient conditions and 2) the early impacts from Macondo crude oil (Table 1). The baseline investigation generated 149 sediment samples from the Louisiana shoreline (Table A3.2a). The overwhelming majority of the sediment samples helped characterize ambient hydrocarbon signatures. However, two percent (3 of 149) of the Nearshore Baseline samples contained Macondo oil (Table A3.2a). These early impacts occurred in Barataria Bay and Chandeleur Sound (Figures 6 and 8). This observation demonstrated the difficulty with identifying reference area in the early phase of the oil spill investigation. The nearshore pre-assessment plan generated 239 sediment samples from the Louisiana shoreline (Table A3.4a). Eighty percent (192 of 239) of the nearshore pre-assessment samples contained Macondo oil (Table A3.4a). The high frequency of Macondo oil detections was consistent with the sampling design that targeted sediments near locations at which SCAT teams observed shoreline oiling. These Macondo impacts occurred in Terrebonne Bay (Figure 5), Barataria Bay (Figure 6), and eastern Bird's Foot Delta (Figure 8).

Combined, the two nearshore sampling plans governed the collection of 388 Louisiana sediment samples from multiple zones:

- Zone A includes between 0 meters and 10 meters from shoreline
- Zone B includes between 10 meters and 20 meters from shoreline

- Zone C includes between 20 meters and 50 meters from shoreline
- Zone D includes between 50 meters and 500 meters from shoreline

The frequency of Macondo oil detections in Pre-assessment samples was high across all of the zones (i.e., 79%, 83%, 83% and 71%, respectively (Table A3.5a). The Macondo oil impacted samples from both SWPs contained $PetPAH_{27}$ with a median concentration of 246 µg/kg and maximum concentration of 11,400 µg/kg (Table A3.1b). The depletion of $PetPAH_{27}$ progressed to a median value of 96% due to the combined effects of continued evaporation and microbial degradation. PAH depletion estimates of Nearshore samples demonstrate that the Macondo oil experienced additional weathering after becoming mixed with the soils and sediments. However, the extent of weathering appears to have reached a maximum of approximately 99% at which point the weathering process slows down for a variety of possible biogeochemical reasons (Table A3.6). A more detailed breakdown of the pre- and post-Macondo sediments by sampling plan and zone are summarized in Appendix 3.

Submerged Oil Sampling Results and Discussion

Nearshore shallow water and benthic habitats are ecologically and economically significant. Benthic marine organisms improve sediment stabilization, water clarity, nutrient cycling, and contaminant removal (Thrush and Dayton 2002). Nearshore habitats serve as nurseries for many marine organisms, including many commercially valuable species, such as brown shrimp, eastern oyster, blue crab, red snapper and blue fin tuna (Sumaila *et al.* 2012). Historical oil spills document losses of ecosystem services; for example, the effects of the Exxon Valdez spill were recognized in Prince William Sound when sampled over ten years after the spill (Peterson 2001, Graham 2003). Therefore, characterizing the nature and extent Macondo oil in nearshore and benthic habitats is an important step in determining potential injury resulting from Macondo oil.

The Fish TWG developed multiple Submerged Oil SWPs to help evaluate subtidal impacts from Macondo crude oil along the northern GOM shoreline (Table 1). This report presents the chemical fingerprinting results of three Submerged Oil investigations executed in Summer 2010, Fall 2010, Winter 2010, and Summer 2011. In total, the Submerged Oil SWPs governed the collection of 1,636 sediment, 481 pom-pom and 1 solid sample from the northern GOM shoreline. However, the sampling strategies in 2010 and 2011 differ significantly in terms of sampling equipment and geography. Therefore, the results of the submerged oil work plan are discussed as three discrete investigations:

- 2010 Pom-Poms,
- 2010 Sediments, and
- 2011 Sediments.

The pom-pom samplers targeted ephemeral oil in the water column and surface sediments. Twenty-eight (28%) percent of the 2010 pom-poms contained Macondo oil (Table A4.1b). The remaining 72% of the samples exhibited no clear evidence of Macondo oil. The frequency of impacted samples declined from Louisiana (74%) to Alabama (47%), Florida (14%) and Mississippi (13%) (Table A4.1b). The highest $PetPAH_{27}$ detection among the 135 pom-poms impacted by Macondo oil occurred in Mississippi (38 ug; Table A4.1d). One pom-pom from Florida captured a solid sample consisting of Macondo oil with a $PetPAH_{27}$ concentration of 2,490,000 µg/kg (Table A4.1d).

The sediment samples collected in 2010 exhibited Macondo oil signatures in 35% of the samples (Table A4.1c). The frequency of Macondo impacts by state are Alabama (47%), followed by Louisiana (39%), Florida (19%), and Mississippi (6%). The $PetPAH_{27}$ concentrations among the 59 sediments impacted by Macondo oil exhibited a different progression: the median $PetPAH_{27}$ declined from Louisiana (413 μg/kg), Florida (109 μg/kg), Mississippi (35 μg/kg), and Alabama (14 μg/kg) (Table A4.1d). These data indicate that the frequency and magnitude of Macondo oil impacts in the submerged sediments varied regionally. Inconsistencies may also reflect the low sample counts.

In 2011, the Macondo oil was recognized in 32% of the submerged oil samples which represented 32% of the 2011 submerged oil sampling sites. The highest percentage of impacted samples/sites occurred in Louisiana (42%/57%) and the lowest percentage of impacted samples/sites occurred in Florida (4%/5%). Intermediate impacts occurred in Alabama (19%/20%) and Mississippi (9%/15%) (Table A4.2a; Table A4.2b). The highest $PetPAH_{27}$ concentration among the 460 impacted sediments occurred in Louisiana ($PetPAH_{27}$ = 58,100 μg/kg dry weight). Similar to the 2010 statistics, the median concentration was lower ($PetPAH_{27}$ = 181 μg/kg dry weight). PAH concentration statistics for impacted submerged oil samples in all states were calculated and reported (Table A4.2c). Maps showing the spatial extent of the 2010 and 2011 impacted submerged oil samples are provided (Figures 2 to 11).

The spatial distribution of submerged oil samples containing Macondo oil varied by state (Figures 2 to 11). The Macondo oil detections in Louisiana occurred around Terrebonne Bay, Barataria Bay, and Bird's Foot Delta. The Macondo oil detections in Mississippi occurred near Cat Island, Ship Island, Horn Island and Petit Bois Island of the Mississippi Barrier Islands and Pascagoula. The Macondo oil detections in Alabama occurred around Dauphin Island, the edge of Mobile Bay and along the Gulf Shores. The Macondo oil detections in Florida appear along the shore between Pensacola and Panama City.

The Macondo oil detections generally occurred within 1 to 2 miles of previously-recognized stranded Macondo oil samples and/or SCAT maximum oiling zones (Figures 2 to 11). Overall, the percentage of Macondo oil detections in 2010 samples exhibited an inverse relationship between Macondo oil detections and distance from shoreline. To highlight these spatial trends, the 2010 pom-pom and sediment samples were broken up into zones based on distance from shoreline during the data analysis process. While these zones were not established by the Fish TWG, they offer insight on the distribution of Macondo oil along the shoreline (Table A4.3; Table A4.4). The zones are defined as follows:

Zone A: Between 0 and 50 meters from shore
Zone B: Between 50 and 500 meters from shore
Zone C: Between 500 and 1,000 meters from shore, and
Zone D: Beyond 1,000 meters from shore

Based the observed deposition of oil close to the shoreline during 2010 Submerged Oil sampling work plans, the 2011 Submerged Oil Field Sampling Plan aimed to focus sampling on the nearshore areas where Macondo oil landed and persisted. To increase the resolution of oiled areas, the Fish TWG established four distinct zones to be sampled along the shorelines of LA, MS, AL and FL (Table A4.5). The four zones are defined as follows:

Zone A: Between 0 and 10 meters from shore
Zone B: Between 10 and 20 meters from shore
Zone C: Between 20 and 50 meters from shore, and
Zone D: Between 50 and 500 meters from shore

The inverse relationship between oiling and distance from the shoreline indicated in 2010 was confirmed in 2011. Within half a kilometer of the shoreline, detection frequencies were comparatively lower in 2011 but the concomitant increase in detections with decreasing offshore distance was apparent. The frequency of Macondo oil detections between 50 and 500 meters observed in 2010 was dampened in 2011.

However, the 2011 occurrence of Macondo oil throughout the 50 meters adjacent to the shoreline was pronounced.

The patterns of *n*-alkanes, acyclic isoprenoids, and PAHs demonstrate that the Macondo oil transformed significantly during migration, deposition, and mixing with background soil. The depletion of $PetPAH_{27}$ in the 2010 Submerged Oil samples progressed from a median of 95% depletion (Table A4.11a) to 97% depletion (Table A4.11b) in 2011. Further weathering is mostly due to the combined effects of continued evaporation and biodegradation. A more detailed breakdown of the Macondo oil in sediments by sampling plan, zone, year, and depth are summarized in Appendix 4.

Oyster Sampling Results and Discussion

Oysters play an important ecological and economic role in the GOM as a keystone species capable of affecting water quality and habitat structure. First, oysters are filter feeders that improve water quality by removing particulates, plankton, and nutrients from the water column (Coen *et al.* 2007; zu Ermgassen *et al.* 2012). Oysters also aggregate to form biogenic reefs that provide a habitat for many aquatic organisms including commercially significant fish (Lenihan *et al.* 2001). Commercial and recreational fishing of both oysters and species reliant on their ecosystem services are a valuable component of the local economy. A decline in oyster populations extends beyond the direct effect on oysters and also threatens the abundance of other proximal species and the local economy.

The Oyster TWG developed SWPs to evaluate the short- and long-term impacts of Macondo oil associated with Eastern Oyster (*Crassostrea virginica*) between July, 2010 and March, 2012. Four SWPs established procedures for assessing oyster abundance, biomass, disease, gonadal condition, larval abundance, and larval settlement. Exposure metrics include the presence of Macondo oil, PAH concentrations in tissues and proximal sediment, and oiling observations. The initial work plans assembled historical oyster data from various state resource agencies. Sampling efforts were then continued for the compilation of baseline conditions and oiled conditions. The proceeding SWPs both sampled additional sites and continued to monitor the previously sampled regions.

Out of the 444 tissue and sediment samples analyzed, 2% were identified as Macondo oil matches (n=8) (Table A5.1a). Infrequent oil was confirmed in both matrices with 1 tissue sample and 7 sediment samples identified as Match Classifications B or C. All Macondo oil detections occurred in Louisiana; the 7 impacted sediment samples were collected in Barataria Bay during late July 2010 and early September 2010. The impacted tissue sample was collected in Terrebonne Bay during Intertidal sampling in February, 2010. Detections indicate low amounts of oil patchily distributed throughout the sampling region's sediments. The lack of oil detected in Eastern oyster tissue samples may be explicated by rapid depuration rates. Studies have shown that after exposure to PAH contaminants, the Eastern oyster can significantly depurate oil from their tissue over the course of 23-52 days (Sericano *et al.* 1996; Anderson 1975; Hwang *et al.* 2004). Therefore, the detection of oil in oyster tissue is contingent upon the temporal relationship between exposure and sample collection.

Rapid depuration of oil in oysters is supported by the results of other studies on the bioaccumulation of contaminants in the Eastern Oyster. In a 2011 report on the impact of the DWH spill on Gulf fisheries, it was observed that when Gulf waters re-opened for oyster fishing on November 15, 2010, sensory analysis of seafood samples had no detectable oil or dispersants. Confirmatory results from chemical analysis showed PAH concentrations were below levels of concern for human consumption (Upton, 2011). In another study, oyster samples were collected from fishing grounds in the Mississippi Gulf coast area. Samples were analyzed weekly from May 27, 2010 to October 2010 then analyzed monthly until August 2011 (n=68). Results showed no significant concentration difference between oyster PAH concentrations in this study and 10 year historical data from NOAA's Mussel Watch program (Xia *et al.* 2012). Lastly, the impact of oiling on the Eastern oyster was evaluated in Louisiana. Results showed that 6 months after the wellhead was capped, no PAHs were detected in oysters collected from sites that were oiled from the DWH spill (Soniat *et al.* 2011).

The highest PAH concentrations among the seven Oyster sediment samples impacted by Macondo oil occurred in Louisiana (Sediment $PetPAH_{27}$ = 705 μg/kg dry weight) with a median $PetPAH_{27}$ equal to 124 μg/kg dry weight (Table A5.5c). The $PetPAH_{27}$ concentration of the impacted tissue sample was 75 μg/kg (Table A5.4b) and it occurred in Terrebonne Bay. All detections were from Louisiana: the areas included Barataria Bay and Terrebonne Bay.

Weathering significantly affected the composition of the spilled oil during its migration from wellhead to shorelines. The Phase I Oyster samples studied herein show that depletion of $PetPAH_{27}$ progressed to a median of 97%, due to the combined effects of continued evaporation and microbial biodegradation. The 5^{th} to 95^{th} percentile of $PetPAH_{27}$ depletion at each individual location ranged from approximately 96% to 98% (Table A5.2a). The percent depletion of the oiled Intertidal Oyster was 73% (Table A5.2b).

A more detailed breakdown of the Macondo oil in the oyster samples by sampling plan, zone, year, and depth are summarized in Appendix 5.

Submerged Aquatic Vegetation Sampling Results and Discussion

Submerged aquatic vegetation (SAV) consists of rooted vascular plants (*e.g.* seagrasses) that primarily exist below the water surface (USEPA, 2006). It is estimated that 10,000 square kilometers of seagrass exists in the northern Gulf of Mexico nearshore environment from Louisiana to Florida (NOAA 2010b). Historically, seagrasses have experienced widespread declines due to a combination of natural and anthropogenic disturbances. Natural disturbances such as hurricanes, earthquakes, disease and over-grazing are commonly associated with the worldwide decline in seagrass cover. In regards to anthropogenic disturbances, reduction in water quality and clarity and direct damage from dredging and similar activities also contribute to the decline in seagrass beds (Short and Wyllie-Echeverria, 1995). The loss of SAV reduces ecological services and impacts the trophic system.

Throughout the Gulf of Mexico, millions of acres of SAV provide important ecological services. SAV beds fill an integral role in bottom-up ecosystems. Through both primary production and serving as a direct food source for marine organisms, SAV support food webs. Other services include providing a habitat and breeding grounds for commercially and recreationally significant fish and aquatic organisms, maintenance and improvement of water quality and the stabilization of sediment and shorelines (Short and Wyllie-Echeverria 1995). Despite their trophic significance, effects of hydrocarbons and dispersants on aquatic plants are largely understudied. Toxicity is a possibility, but specifics effects are not well understood (Lewis and Pryor 2013). Therefore, the ecological and economic significance of SAV in combination with the concurrent lack of knowledge regarding its response to hydrocarbon exposure emphasizes the importance of measuring the impact of Macondo Oil on SAV habitats.

This report presents the chemical fingerprinting results associated with four SAV sampling work plans (SWP) implemented between May 3, 2010 and June 22, 2011. The SWPs governed the collection of 508 pom-pom, 125 solid, 229 sediment, 414 tissue and 2 sheen samples. In total, Macondo Oil was recognized in 25% (318 of 1,278) of the samples and the rest were Indeterminate (Table A6.1a). The highest percentage of impacted samples occurred in Alabama (45%) and the lowest percentage of impacted samples occurred in Louisiana (15%). Intermediate impacts occurred in Mississippi (26%) and Florida (18%). Maps showing the spatial extent of impacted samples are provided (Figures 2-11).

The highest $PetPAH_{27}$ concentration among the solid samples (soil, sediments, particulates) occurred in Louisiana ($PetPAH_{27}$=1,590,000 µg/kg dry weight) during Tier 2 sampling, although the median PAH concentration among impacted Louisiana solid samples was much lower (81 µg/kg dry weight) (Table A6.3a). Among impacted tissue samples, the highest $PetPAH_{27}$ concentration occurred in a Tier 2 Louisiana sample ($PetPAH_{27}$=28,500 µg/kg). Again, the median PAH concentration among impacted Louisiana tissue samples was much lower ($PetPAH_{27}$=110 µg/kg) (Table A6.3a). Finally, among the impacted pom-pom and sheen samples, the highest $PetPAH_{27}$ concentration occurred in Mississippi during Tier 2 sampling. The $PetPAH_{27}$ detection was 38 µg (Table A6.3a). The median detection of all impacted pom-pom and sheen samples was 0.59 µg (Table A6.3a).

Combined, the SAV SWPs characterized the temporal and spatial occurrence of oil. As of June 11, 2010, oil was not detected amongst the sampled SAV beds (Table 6.1b). Between June 11, 2010 and mid-August, 2010, the beginning of Tier 2 sampling, oil released from the wellhead reached SAV beds in Louisiana, Mississippi, Alabama and Florida (Table A6.1c). Louisiana, the most western portion of the study area, exhibited the greatest percentage of oiled sediment and tissue samples. Conversely, pom-poms were the most frequently oiled matrix in the remaining states, identifying the water column as a potential route of SAV exposure to Macondo oil (Table A6.5). Pom-poms had the largest sample count with lower numbers present for sediments and tissues. Tier 2 (LA, MS, Al, FL) and Tier 3 (LA) samples were collected from four zones:

- Zone A includes between 0 meters and 50 meters from shoreline
- Zone B includes between 50 meters and 150 meters from shoreline
- Zone C includes between 150 meters and 500 meters from shoreline
- Zone D includes beyond 500 meters from shoreline

Fresh and Brackish Water sampling focused closer to the shore. During Tier 2 sampling, the occurrence of Macondo Oil was high throughout Zone A in Louisiana and Mississippi. Detection frequencies generally declined as distance from the shoreline increased, particularly in Mississippi. Alabama and Florida had a more heterogeneous occurrence of Macondo Oil. Fresh and Brackish Water sampling and Tier 3 sampling confirmed the increased frequency of oil close to the Louisiana shoreline over time. In total, the SAV results exhibit a trend of oil accumulating along the shoreline where it is deposited and mixes with surrounding sediments (Table A6.8; Table A6.9; Table A6.10). Following Tier 2 sampling, the frequency of Macondo oil detections often declined. The samples studied herein show that the depletion of $PetPAH_{27}$ progressed to a median of 95% in Tier 3 samples, the last SAV SWP (Table A6.11). A more detailed breakdown of SAV results by sampling plan, matrix and zone are summarized in Appendix 6.

Miscellaneous Sampling Results

While the majority of field sampling plans were designed and implemented to produce large, comprehensive sets of data, some were executed as narrowly defined evaluations. Although conditions evaluated by these sampling plans were not continuously monitored, they do provide insight on the occurrence of Macondo oil. Three work plans are included in this section:

(1) National Oceanic and Atmospheric Administration Assessment and Restoration Division (NOAA ARD)-2010
(2) Fish—Pre-assessment Fish Kill-2010
(3) Toxicity Sediment Collection-2010/2011

NOAA ARD

The Macondo oil release was unexpected and the earliest work plans were not necessarily written at the time of sampling. The NOAA ARD samples included in this report under the NOAA ARD study were collected between April 29, 2010 and May 2, 2010. The results from this sample collection effort represent sediments along the northern Gulf of Mexico shoreline just 9 days after the first release from the wellhead.

Field teams collected 44 sediment samples proximal to the shorelines of Louisiana, Mississippi, Alabama and Florida. In total, Macondo oil was not recognized in any of the samples (Table A7.1). The absence of Macondo oil indicates that at the time of NOAA ARD sample collection, oil had not yet reached the shoreline or come in contact with the sediment. Accordingly, a subset of these samples was integrated into the Pre-Oil section, providing a baseline. The $PetPAH_{27}$ concentration in NOAA ARD samples varied by location with a median $PetPAH_{27}$ concentration of 0.06 µg/kg dry in Louisiana and below detection in other states (Table A7.2).

Fish Kill

Shortly after the Deepwater Horizon Oil Spill, fish kills were reported inshore and offshore throughout the north-central Gulf of Mexico. Due to their sensitivity to local stressors, the observance of fish mortality and sublethal stress (reduced fitness and decreased reproductive success) could provide indicators of large-scale adverse effects; possibly resulting from exposure to Macondo oil. To measure the relationship between observed mortality of marine life and the presence of Macondo oil and dispersants, the Fish TWG developed the *Investigative Plan for Fish and Invertebrate Kills in the Northern Gulf of Mexico*.

Under this work plan, locations of reported fish kills were visited by field teams. Upon arrival, the team evaluated the relative severity of the fish kill by observing the level of oiling and quantifying the presence of dead fish. If dead or moribund fish were present, sediment, water and tissue samples were taken opportunistically. Sediment samples were collected using a ponar grab sampler and tissue samples consisted of dead organisms observed and collected on-site. Between 2010 and 2011, 24 samples were collected under this work plan that were analyzed and are discussed in this report. Samples were collected during September, October and December of 2010 and February of 2011 in Louisiana, Florida and Mississippi.

All sediments were from Louisiana and none were determined to contain Macondo oil, resulting in 4 Indeterminate samples. Similarly, 18 Indeterminate tissues were collected from Louisiana and Mississippi. Conversely, the two solid samples collected from Florida in December were both determined to contain relatively pure Macondo oil (Classification Code A). A summary of Macondo oil detections has been compiled and reported (Table A7.3).

Of the samples containing Macondo oil, the maximum $PetPAH_{27}$ concentration was 1,420,000 µg/kg (n=2). The median value was only slightly less with a concentration of 1,250,000 µg/kg. PAH statistics have been calculated and reported (Table A7.4).

Toxicity Sediment Collection-2010/2011

Concurrent to the execution of contaminant characterization plans discussed thus far in this report were a variety of studies focused on characterizing the biological and toxicological effects of Macondo oil. For example, one work plan titled *Aquatic Toxicity Test Program: Evaluate the Potential Acute and Chronic Toxicity of the MC-252 Crude Oil and Dispersant (Corexit 9500) individually and in Combination, as well as the Weathered Crude and Weathered Dispersed Oils, to Estuarine and Marine Organisms* collected field sediment and water samples to study the biological effects and environmental fate of Macondo oil contaminants in sediment-water systems. Toxicity samples were collected both independent from and simultaneously with Nearshore field sampling plans.

The 2010 Toxicity Sediment Collection occurred on August 22, 2010. A field sampler accompanied a submerged oil collection team under the Fish TWG and sampled tar mats as they occurred on the beach. Conversely, the 2011 toxicity samples were not collected alongside a nearshore sampling work plan. In total, 8 toxicity samples have been analyzed and are summarized in this report. In 2010, 3 solid samples were collected in Louisiana and 100% of the samples were determined to be a Match Classification A (Table A7.5a). In 2011, 5 sediment samples were collected from Louisiana. 40% of the sediment samples were determined to be a Match Classification A (n=2). The remaining 60% of the samples were considered to be Indeterminate (Table A7.5b).

Of the three solid samples tested as part of the toxicity testing program, the median $PetPAH_{27}$ concentration was 3,030,000 µg/kg (Table A7.6a). The sediment samples containing Macondo oil in 2011 contained lower median $PetPAH_{27}$ concentrations (10,000 µg/kg dry weight; Table A7.6b). The large difference between the $PetPAH_{27}$ concentrations in the samples collected from tar mats versus the sediment samples exemplifies the effects of weathering and mixing on the Macondo oil composition.

Conclusion

The *Deepwater Horizon* NOAA NRDA oil spill response included the creation of more than 23 sampling work plans for the collection of 5,605 environmental samples between 2010 and 2012 along the coastlines of Louisiana, Mississippi, Alabama, and Florida and proximal waters within 3 nautical miles of the northern Gulf of Mexico shoreline. Field teams collected and analyzed 511 soil, 3,222 sediment, 132 solid, 1,003 pom-pom, 2 sheen, 732 tissue, and other samples. The hydrocarbon patterns in these samples were chemically analyzed and forensically compared to fresh and weathered Macondo oil reference samples. The chemical composition and spatial distribution of hydrocarbon signatures distinguished Macondo oil from ambient hydrocarbons and helped identify the areas with potential human and ecological impacts.

The primary investigations focused on shoreline areas, coastal wetland vegetation, submerged aquatic vegetation, nearshore areas, oysters, submerged oil, and others. Several smaller studies provided supplemental information for the research and development of analytical methods, fish kills, toxicity studies, and baseline surveys. The chemical fingerprinting results demonstrated that Macondo oil traveled from the wellhead to the shorelines of Louisiana, Mississippi, Alabama and Florida. The chemical fingerprint of Macondo oil extended west to Atchafalaya Bay, Louisiana and east to Apalachicola, Florida. The highest PAH concentrations occurred in stranded oil and pom-pom samples throughout the study area. The highest overall PAH concentrations among the sediment/soil/solid samples and tissue samples occurred in Bay Jimmy, Louisiana and along the Louisiana barrier islands. The concentration of the Macondo oil generally declined during the study period, especially in areas where the oil mixed with shallow soil and sediment.

The chemical fingerprint of the Macondo oil changed as a result of chemical, physical and biological weathering both during the oil's migration from the wellhead to the shoreline and after deposition along the shoreline environments. Previously-studied floating oil samples demonstrated a median $PetPAH_{27}$ depletion of 65% that increased to 94% among stranded oil samples, mostly due to evaporation. After deposition, the $PetPAH_{27}$ depletion progressed to a median of 97% in the upland and 87% in the submerged sediment environments due to the continued effect of evaporation and dissolution augmented by microbial biodegradation. The degree of weathering may serve as a useful line of evidence to help identify the likely upland/offshore origin of remobilized Macondo oil that appears in the nearshore environment from time to time. A database of the forensic hydrocarbon results for the nearshore samples collected in Louisiana, Mississippi Alabama and Florida in this report are compiled by sample, geographical location, depth, matrix, and sampling plan.

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Figures and Tables Summarizing All Nearshore Sample

Table 1. Nearshore Sample Summary Information.

Technical Work Group	Study Name	Sampling Work Plan	Matrix	Count	Sample Collection Start	Sample Collection End	Appendix
Shoreline	Shoreline--Baseline--2010	No Formal Workplan	Other	3	5/24/2010	5/25/2010	
			Sediment	20	5/24/2010	5/26/2010	
	Shoreline-Coastal Wetland Vegetation Plan: 2010	Sampling and Monitoring Plan for the Assessment of MC252 Oil Impacts to Coastal Wetland Vegetation in the Gulf of Mexico	Sediment	604	9/16/2010	4/11/2011	2
	Shoreline-Coastal Wetland Vegetation Plan: Spring 2011		Soil	511	4/9/2011	6/8/2011	
			Solid	1	5/16/2011	5/16/2011	
	Shoreline-Coastal Wetland Vegetation Plan: Marsh Response Cleanup--FEB 2011	Addendum to the Sampling and Monitoring Plan for Coastal Wetland Vegetation - Protocol for Sampling and Monitoring Marsh Response Cleanup Areas	Sediment	56	2/21/2011	2/25/2011	
Nearshore	Nearshore Sediment & Water: Baseline--Late JUN 2010	Work Plan for Sediment and Water Collection and Analyses for Baseline NRDA Purposes in Louisiana	Sediment	149	6/21/2010	7/16/2010	3
	Nearshore Sediment & Water: Baseline--Early JUL 2010						
	Nearshore Sediment & Water: Baseline--Late JUL 2010						
	Nearshore Sediment & Water: Preassessment-Early AUG 2010	Pre-Assessment Phase Water Sampling for NRDA Purposes in Louisiana	Sediment	239	8/6/2010	12/3/2010	
	Nearshore Sediment & Water: Preassessment-Late AUG 2010						
	Nearshore Sediment & Water: Preassessment-Early SEP 2010						
	Nearshore Sediment & Water: Preassessment-Late SEP 2010						
	Nearshore Sediment & Water: Preassessment-Early OCT 2010						
	Nearshore Sediment & Water: Preassessment-Late OCT 2010						
	Nearshore Sediment & Water: Preassessment-Early NOV 2010						
	Nearshore Sediment & Water: Preassessment-Late NOV 2010						
	Nearshore Sediment & Water: Preassessment-Early DEC 2010						
Fish	Fish Preassessment: Submerged Oil Collection--2010	Nearshore Water Column Injury Ephemeral Data Collections: Submerged Oil Reconnaissance Plan	Sediment	11	7/17/2010	7/20/2010	4
			Pom-Pom	54	9/7/2010	9/10/2010	
	Fish Preassessment: Submerged Oil Characterization--2010	Nearshore Ephemeral Data Collections: Submerged Oil Characterization Across Multiple Habitats Deepwater Horizon Oil Spill (DWHOS)	Sediment	156	9/17/2010	11/18/2010	
			Pom-Pom	427	9/17/2010	12/15/2010	
			Pom-Pom/Solid	1	11/10/2010	11/10/2010	
	Fish Submerged Oil Characterization Plan: Marsh Edge and Sandy Shoreline (MESSh)--2011	Submerged Oil Characterization Across Multiple Habitats for Assessment of Persistent Exposes in Nearshore Sediments	Sediment	1,469	6/6/2011	8/9/2011	
Oysters	Preassessment-OysterSampling--2010	Mississippi Canyon 252 Spill Oyster Sampling Plan Phase I – High Priority Sites	Sediment	123	7/22/2010	10/6/2010	5
			Tissue	254	8/26/2010	11/22/2010	
	Preassessment-OysterTransition--2011	Mississippi Canyon 252 Spill Oyster Sampling Transition Plan	Sediment	25	2/17/2011	2/21/2011	
			Tissue	4	2/17/2011	2/21/2011	
	Spring 2011 Oyster Recruitment Sampling	Spring 2011 Oyster Recruitment Sampling Plan	Tissue	2	6/27/2011	6/27/2011	
	Intertidal Oyster Quadrat Sampling--2012	Oyster Sampling Plan 2012 Intertidal Oyster Quadrat Sampling	Tissue	36	2/15/2012	3/16/2012	
Submerged Aquatic Vegetation	SAV--Baseline-Tier 1--2010	Mississippi Canyon 252 Oil Spill Submerged Aquatic Vegetation Tier 1 Pre-Assessment Plan Pre-Impact Baseline Characterization	Sediment	93	5/3/2010	6/11/2010	6
			Solid	12	6/2/2010	6/2/2010	
			Tissue	177	6/2/2010	6/22/2010	
	SAV--Preassessment Tier 2--Early AUG 2010	Mississippi Canyon 252 Oil Spill Submerged Aquatic Vegetation Tier 2 Pre-Assessment Plan Post Spill Exposure Characterization Plan	Pom-Pom-Solid	3	8/2/2010	8/7/2010	
			Sediment	73	8/2/2010	9/16/2010	
			Solid	85	8/2/2010	9/16/2010	
	SAV--Preassessment Tier 2--Late AUG 2010		Sheen	2	8/4/2010	8/23/2010	
			Pom-Pom	508	8/13/2010	9/11/2010	
	SAV--Preassessment Tier 2--Late SEP 2010		Tissue	137	8/24/2010	9/16/2010	
	SAV--Tier 3--2011	Tier 3: Injury Assessment Plan for Submerged Aquatic Vegetation: Chandeleur Island, Louisiana	Sediment	52	6/20/2011	6/22/2011	
			Solid	25			
			Tissue	56			
	SAV--Freshwater/Brackish--2010/2011	NRDA Work Plan for Assessing Potential Impacts to Fresh and Brackish Water Submerged Aquatic Communities	Sediment	11	12/14/2010	1/20/2011	
			Tissue	44	12/14/2010	1/28/2011	
Chemistry	Forensic Oil Sampling April 2010	Work Plan for Obtaining Near Shore Spatial Extent of On-Water Oil Samples	Pom-Pom	14	9/5/2010	9/5/2010	7
Other NOAA	NOAA Assessment and Restoration Division--2010	No Formal Workplan	Sediment	44	4/29/2010	5/2/2010	8
	Toxicity Sediment Collection-2010	Nearshore Water Column Injury Ephemeral Data Collections: Submerged Oil Reconnaissance Plan	Solid	3	8/22/2010	8/22/2010	9
	Toxicity Sediment Collection-2011	No Formal Workplan	Sediment	5	1/25/2011	1/26/2011	
	Fish Kill--2010	Fish Kill Plan-Investigative Plan For Fish and Invertebrate Kills in the Northern Gulf of Mexico	Sediment	4	9/18/2010	9/18/2010	10
			Solid	2	12/5/2010	12/5/2010	
	Fish Kill--2011		Tissue	18	9/16/2010	2/16/2011	
State	MDEQ Preassessment Late April 2010	State Workplan	Tissue	4	4/29/2010	4/29/2010	
	MDEQ Preassessment Early May 2010		Sediment	56	4/29/2010	5/4/2010	
	FLDEP-Baseline Early May 2010	State Workplan	Sediment	32	5/1/2010	5/21/2010	
	FLDEP-Baseline Late May 2010						
		Total		5,605	4/29/2010	3/16/2012	

Table 2. Nearshore Forensic Classification Codes by Study Name.

Study	Count	Percent Samples by Classification Code				
		A	B	C	D	E
Shoreline--Baseline--2010	23	0%	0%	0%	100%	0%
Shoreline-Coastal Wetland Vegetation Plan--2010	601	22%	29%	9%	40%	0%
Shoreline-Coastal Wetland Vegetation Plan--Spring 2011	515	15%	23%	15%	47%	0%
Shoreline--CWV Marsh Response Cleanup--FEB 2011	56	89%	11%	0%	0%	0%
Nearshore Sed & Water--Baseline--Late JUN 2010	89	0%	2%	0%	98%	0%
Nearshore Sed & Water--Baseline--Early JUL 2010	54	0%	2%	0%	98%	0%
Nearshore Sed & Water--Baseline--Late JUL 2010	6	0%	0%	0%	100%	0%
Nearshore Sed & Water-Preassessment-Early AUG 2010	53	8%	51%	30%	11%	0%
Nearshore Sed & Water--Preassessment-Late AUG 2010	61	26%	38%	16%	20%	0%
Nearshore Sed & Water--Preassessment-Early SEP 2010	31	6%	48%	23%	23%	0%
Nearshore Sed & Water--Preassessment-Late SEP 2010	2	0%	100%	0%	0%	0%
Nearshore Sed & Water--Preassessment-Early OCT 2010	51	4%	14%	61%	22%	0%
Nearshore Sed & Water--Preassessment-Late OCT 2010	13	0%	15%	46%	38%	0%
Nearshore Sed & Water--Preassessment-Early NOV 2010	12	0%	17%	75%	8%	0%
Nearshore Sed & Water--Preassessment-Late NOV 2010	10	0%	0%	90%	10%	0%
Nearshore Sed & Water--Preassessment-EarlyDEC2010	6	0%	17%	17%	67%	0%
Fish--Preassessment-Submerged Oil Collection--2010	65	3%	6%	55%	35%	0%
Fish--Preassessment-Submerged Oil Characterization--2010	584	13%	7%	6%	74%	0%
Fish--Submerged Oil Chaaracterization Plan--MESSh--2011	1,469	3%	12%	17%	68%	0%
Oyster--Preassessment-Oyster Sampling--2010	377	0%	2%	0%	98%	0%
Oyster--Preassessment-Oyster Transition--2011	29	0%	0%	0%	100%	0%
Oyster--Spring 2011 Oyster Recruitment Sampling	2	0%	0%	0%	100%	0%
Oyster--Intertidal Oyster Quadrat Sampling--2012	36	0%	0%	3%	97%	0%
SAV--Baseline-Tier 1--2010	282	0%	0%	0%	100%	0%
SAV--Preassessment Tier 2--Early AUG 2010	83	6%	27%	23%	45%	0%
SAV--Preassessment Tier 2--Late AUG 2010	483	2%	16%	26%	56%	0%
SAV--Preassessment Tier 2--Early SEP 2010	205	4%	6%	9%	81%	0%
SAV--Preassessment Tier 2--Late SEP 2010	37	0%	0%	11%	89%	0%
SAV--Tier 3--2011	133	1%	5%	1%	93%	0%
SAV--Freshwater/Brackish--2010/2011	55	0%	2%	11%	87%	0%
Chemistry--Forensic Oil Sampling APR 2010	14	0%	14%	29%	57%	0%
NOAA Assessment and Restoration Division--2010	44	0%	0%	0%	100%	0%
Toxicity Sediment Collection--2010	3	100%	0%	0%	0%	0%
Toxicity Sediment Collection--2011	5	40%	0%	0%	60%	0%
Fish--Preassessment-Fish Kill--2010	22	9%	0%	0%	91%	0%
Fish--Preassessment-Fish Kill--2011	2	0%	0%	0%	100%	0%
MDEQ--Preassessment--Late APR 2010	18	0%	0%	0%	100%	0%
MDEQ Preassessment Early MAY 2010	42	0%	0%	0%	100%	0%
FLDEP--Baseline--Early MAY 2010	29	0%	0%	0%	100%	0%
FLDEP--Baseline--Late MAY 2010	3	0%	0%	0%	100%	0%
Total	5,605	8%	13%	13%	66%	0%

Table 3. Nearshore Forensic Classification Codes By State.

Category	Louisiana	Mississippi	Alabama	Florida	All States
Total Samples	3,229	715	749	912	5,605
Classification Codes A+B+C	1,417	111	245	109	1,882
Classification Code A	324	18	66	22	430
Classification Code B	571	24	117	22	734
Classification Code C	522	69	62	65	718
Indeterminate Code D	1,811	604	504	803	3,722
Non-Match Code E	1	-	-	-	1
% Classification Codes A+B+C	44%	16%	33%	12%	34%
Classification Code A	10%	3%	9%	2%	8%
Classification Code B	18%	3%	16%	2%	13%
Classification Code C	16%	10%	8%	7%	13%
Indeterminate Code D	56%	84%	67%	88%	66%
Non-Match Code E	0%	0%	0%	0%	0%

Table 4. PetPAH$_{27}$ Concentrations in Solid Samples with Macondo oil By State.

Category	Louisiana	Mississippi	Alabama	Florida	All States
Solid (Soil, Sediments, Particulates) PetPAH$_{27}$ µg/kg dry in Classification Codes A+B+C					
Count	1,340	32	72	18	1,462
Minimum	nd	4.3	nd	3.6	nd
5th Percentile	49	15	1.2	8.2	26
25th Percentile	132	37	11	58	119
50th Percentile (Median)	317	189	27	328	287
75th Percentile	1,130	344	106	674	994
95th Percentile	29,200	433,000	3,300	1,580,000	30,400
Maximum	3,280,000	1,280,000	340,000	2,490,000	3,280,000

na - not analyzed nd - not detected no - not observed

Table 5. $PetPAH_{27}$ Concentrations in Tissue Samples with Macondo oil By State.

Category	Louisiana	Mississippi	Alabama	Florida	All States
Tissue $PetPAH_{27}$ µg/kg dry Classification Codes A+B+C					
Count	19	1	na	na	20
Minimum	8.0	569	na	na	8.0
5th Percentile	21	569	na	na	22
25th Percentile	50	569	na	na	52
50th Percentile (Median)	107	569	na	na	108
75th Percentile	633	569	na	na	629
95th Percentile	7,310	569	na	na	6,130
Maximum	28,500	569	na	na	28,500

na - not analyzed nd - not detected no - not observed

Table 6. PetPAH$_{27}$ Detections in Pom-Pom Samples with Macondo oil By State.

Category	Louisiana	Mississippi	Alabama	Florida	All States
Pom-Pom PetPAH$_{27}$ µg Classification Codes A+B+C					
Count	58	77	172	91	398
Minimum	0.24	0.27	0.01	0.29	0.01
5th Percentile	0.31	0.29	0.33	0.32	0.30
25th Percentile	0.47	0.40	0.58	0.44	0.46
50th Percentile (Median)	0.66	0.50	0.83	0.59	0.66
75th Percentile	0.96	0.67	1.4	0.93	1.0
95th Percentile	1.5	4.8	8.7	2.0	5.4
Maximum	4.9	38	36	5.8	38

na - not analyzed nd - not detected no - not observed

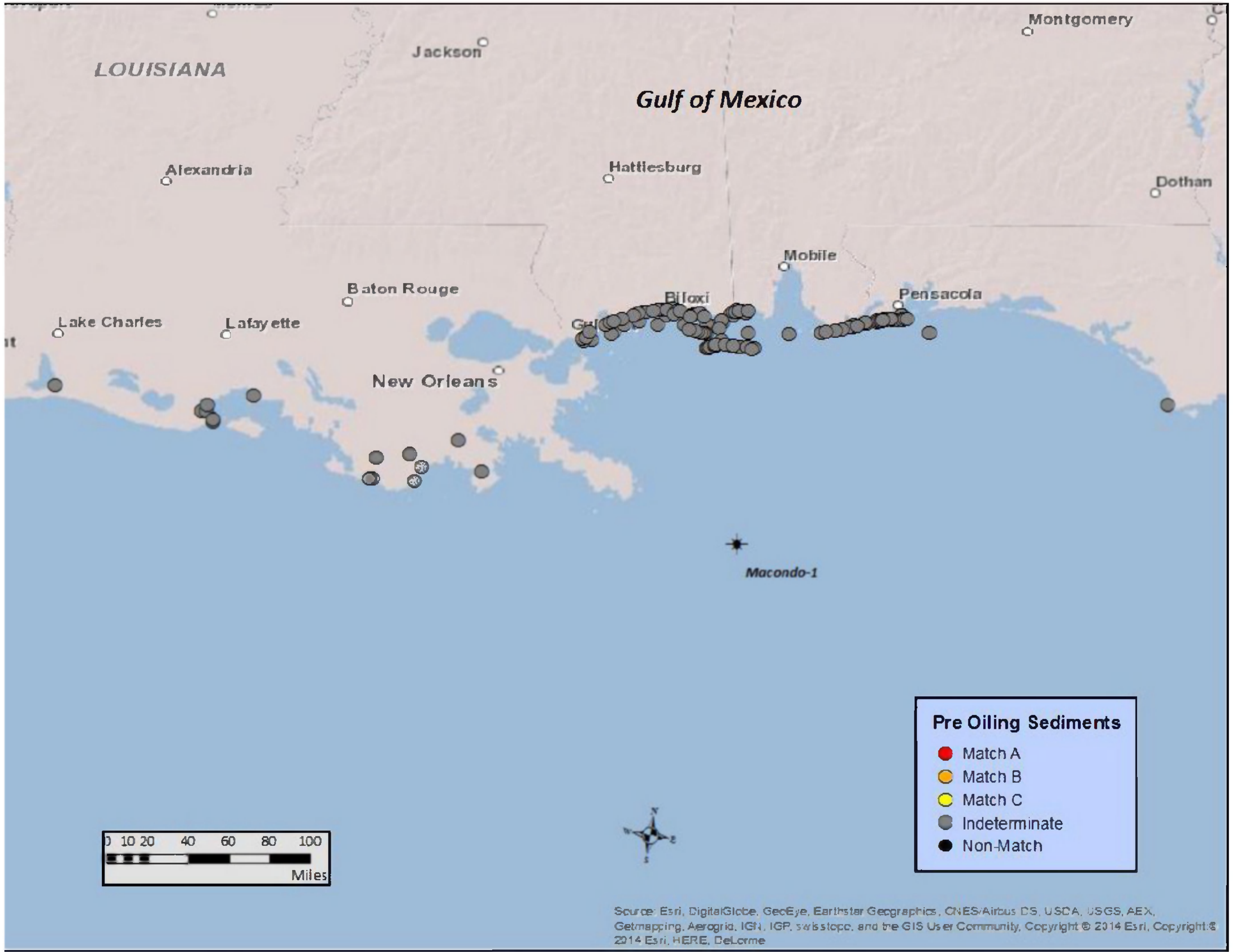

Figure 1. Pre-Oil Sample Locations.

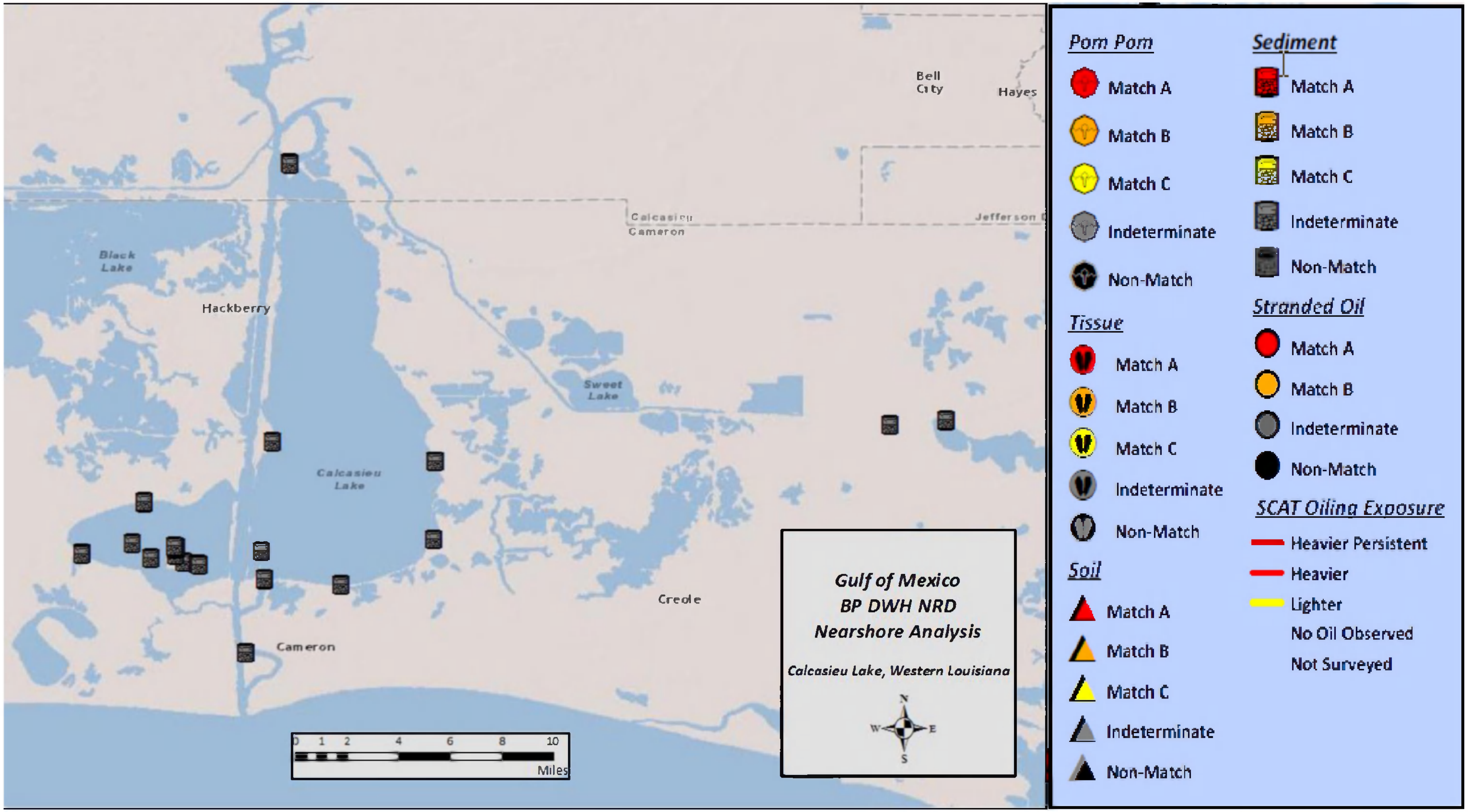

Figure 2. Nearshore Samples Collected in Calcasieu Lake, West Louisiana.

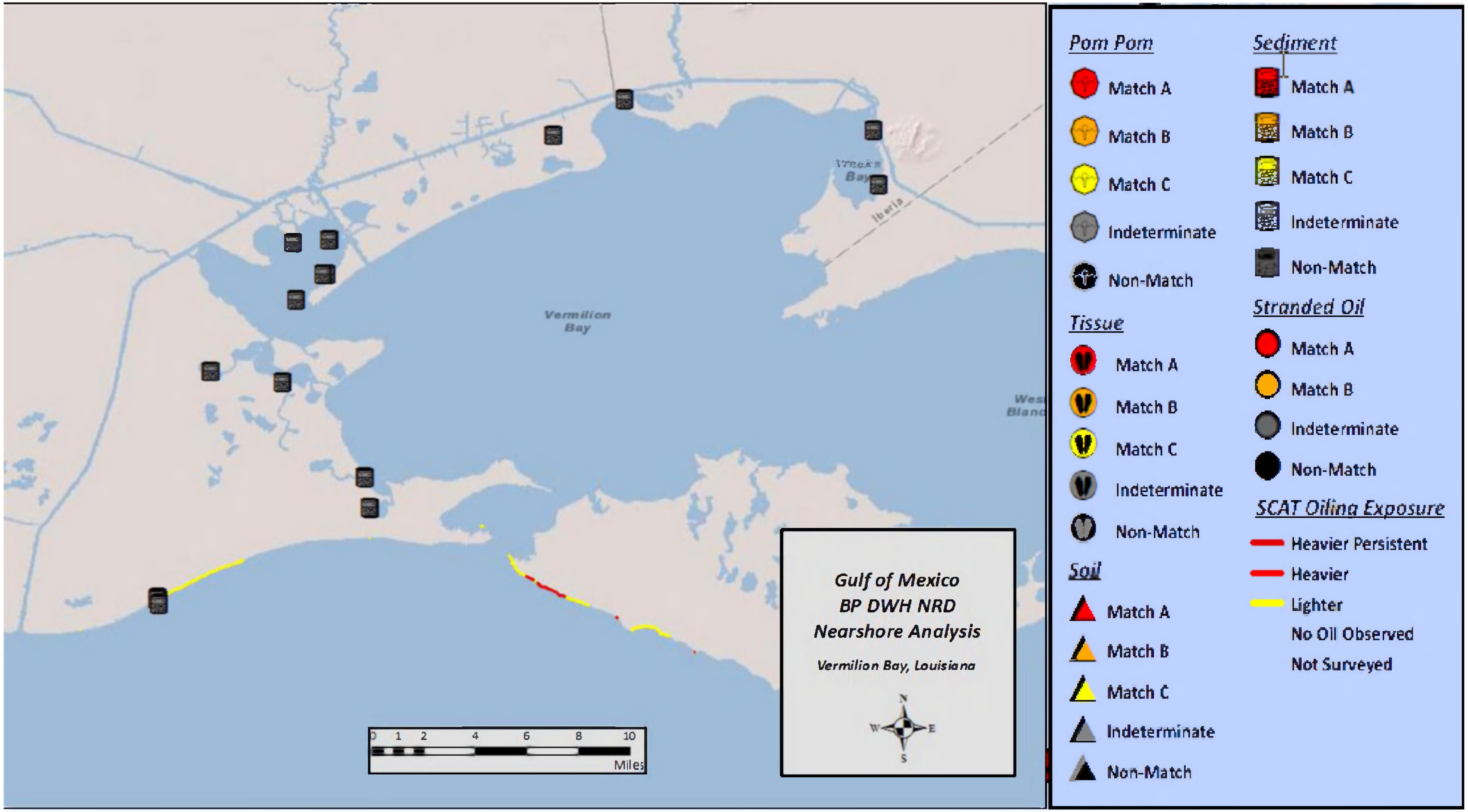

Figure 3. Nearshore Samples Collected in Vermilion Bay, Louisiana.

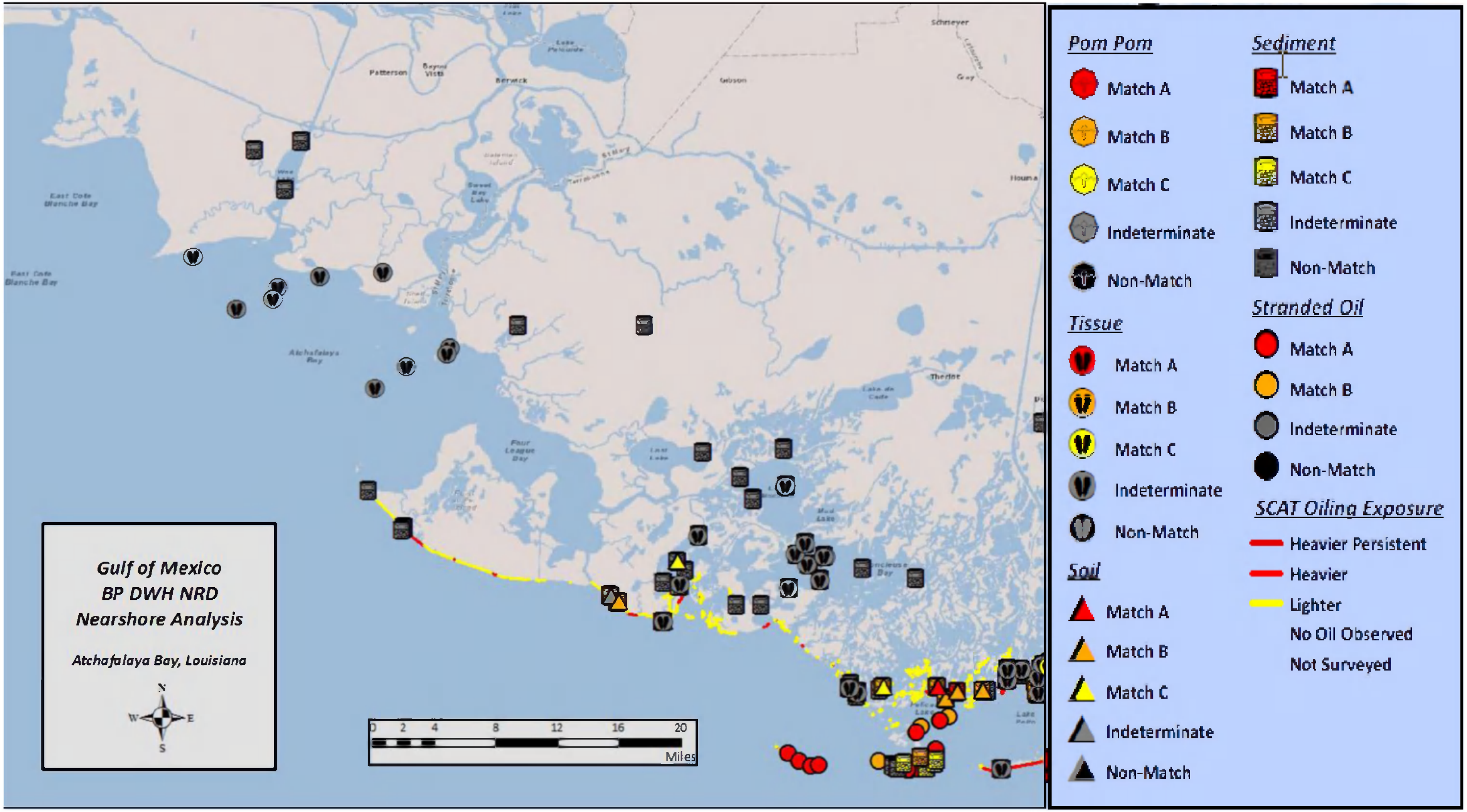

Figure 4. Nearshore Samples Collected in Atchafalaya Bay, Louisiana.

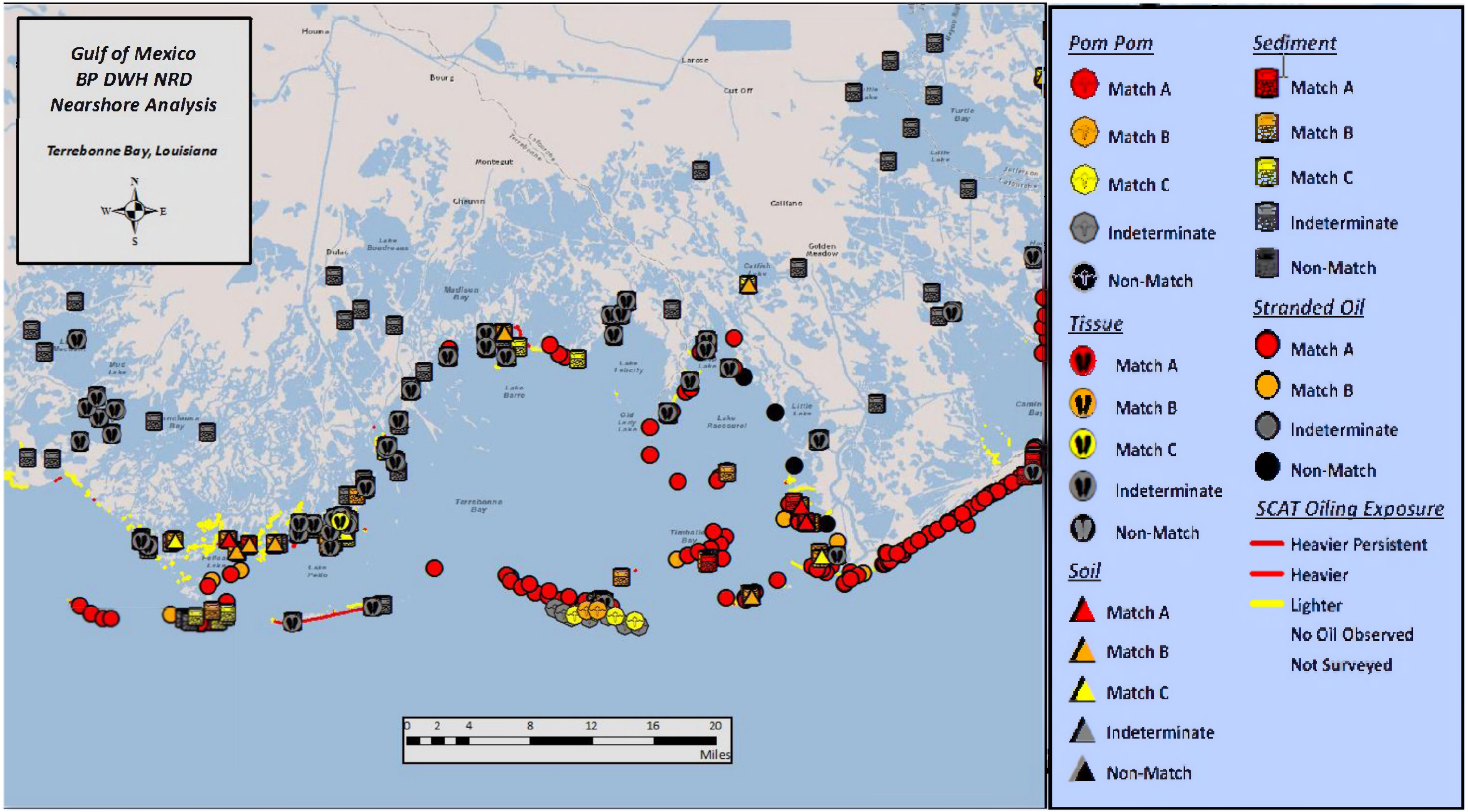

Figure 5. Nearshore Samples Collected in Terrebonne Bay, Louisiana.

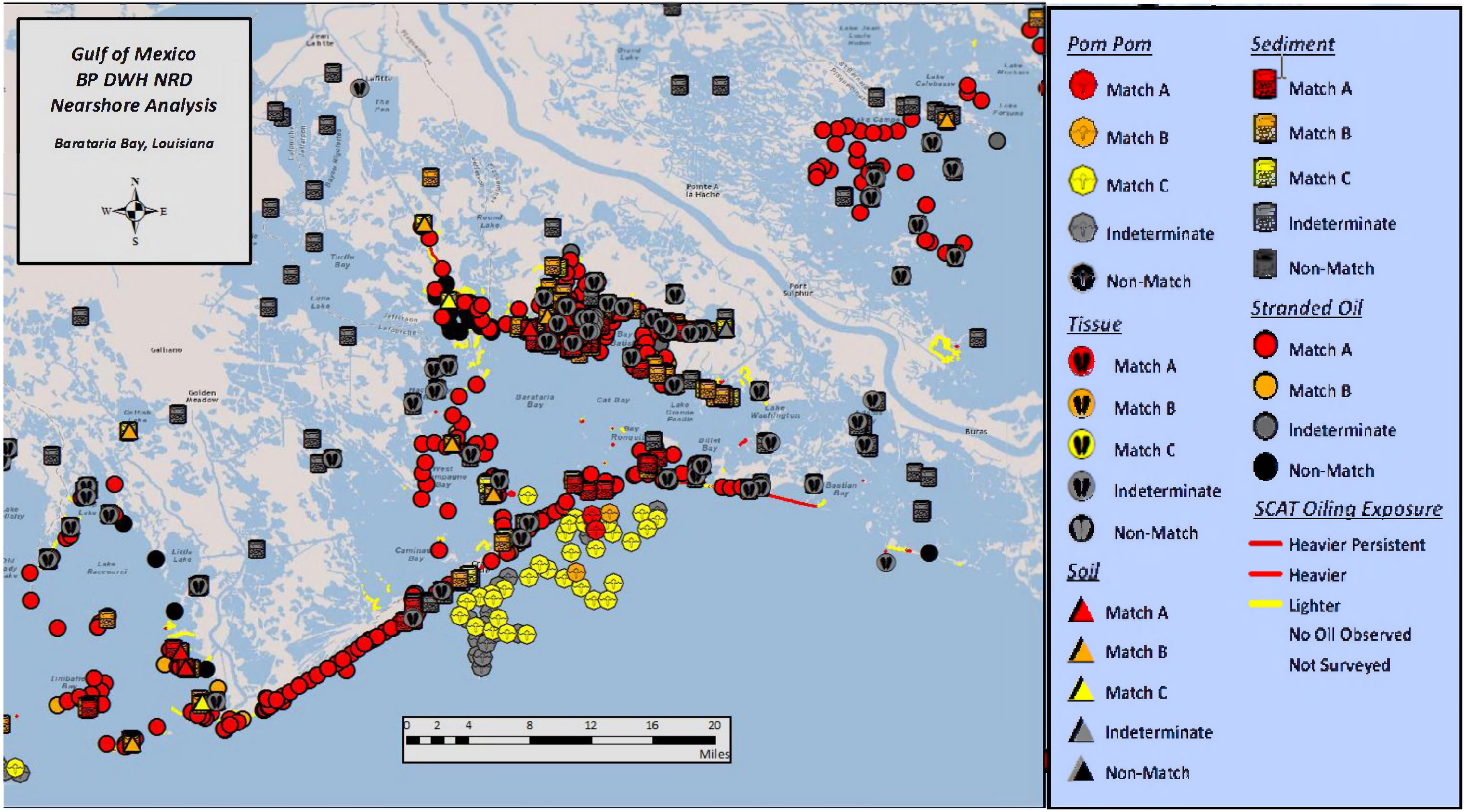

Figure 6. Nearshore Samples Collected in Barataria Bay, Louisiana.

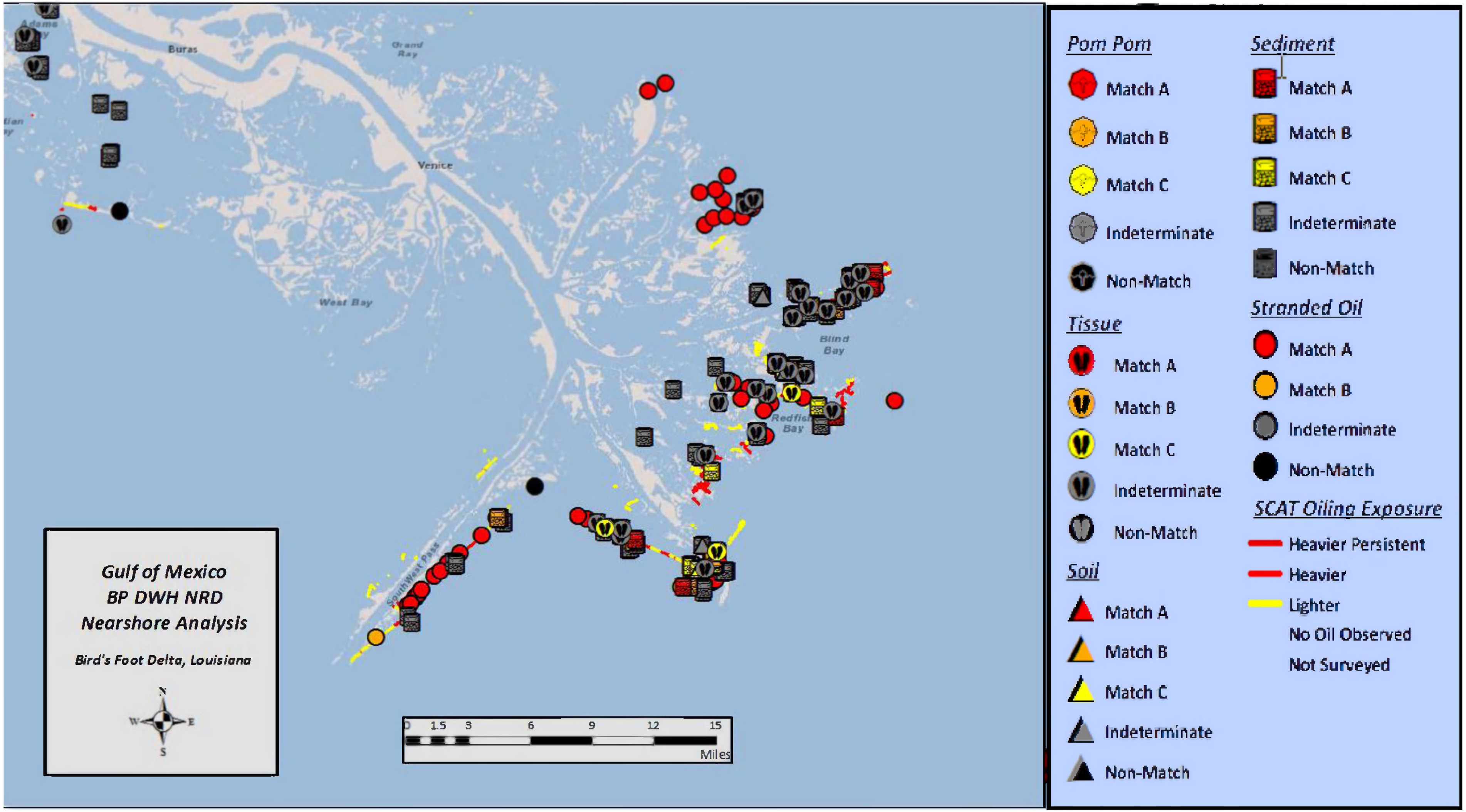

Figure 7. Nearshore Samples Collected in Bird's Foot Delta, Louisiana.

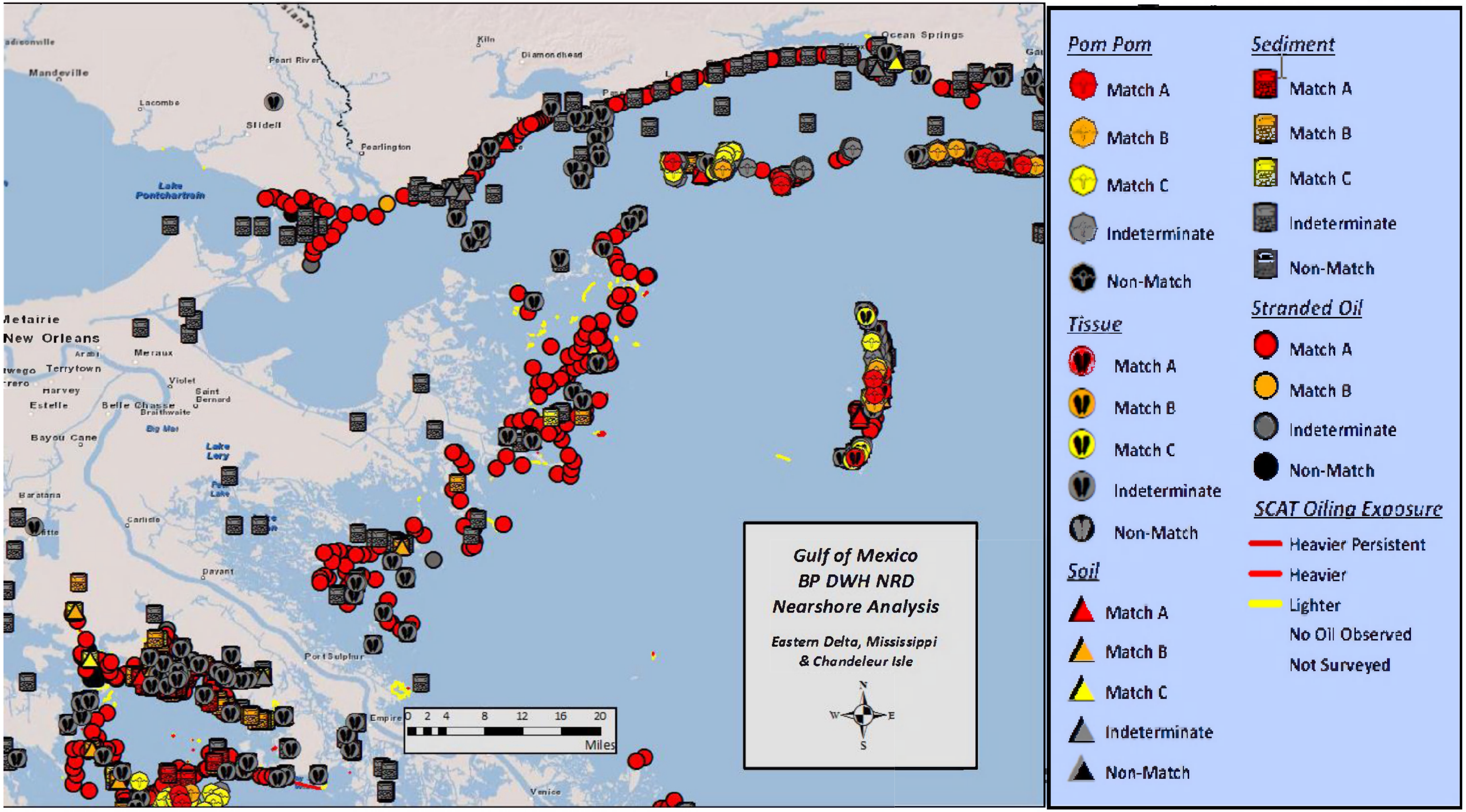

Figure 8. Nearshore Samples Collected in Eastern Delta, Mississippi and Chandeleur Isle, Mississippi.

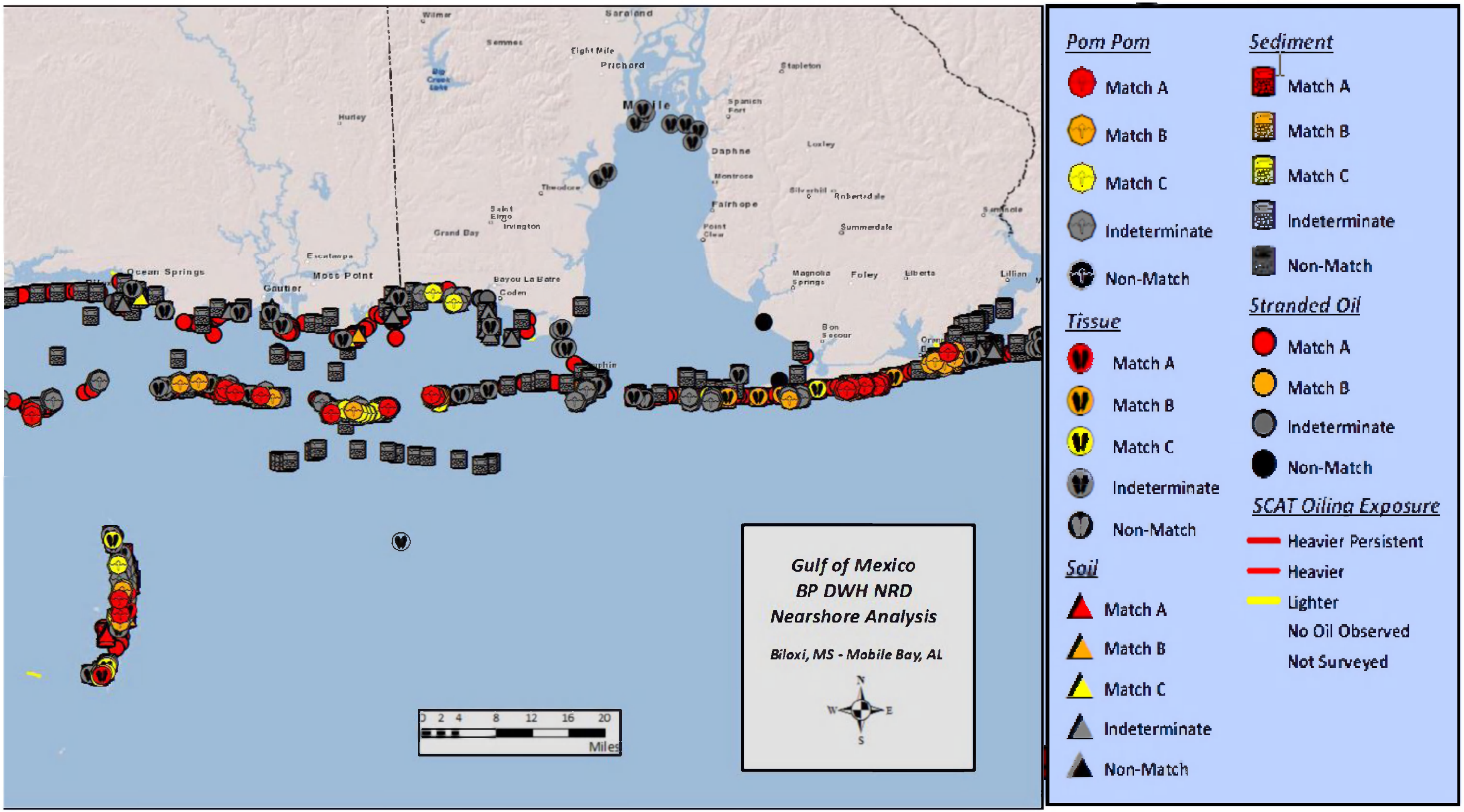

Figure 9. Nearshore Samples Collected from Biloxi, Mississippi to Mobile Bay, Alabama.

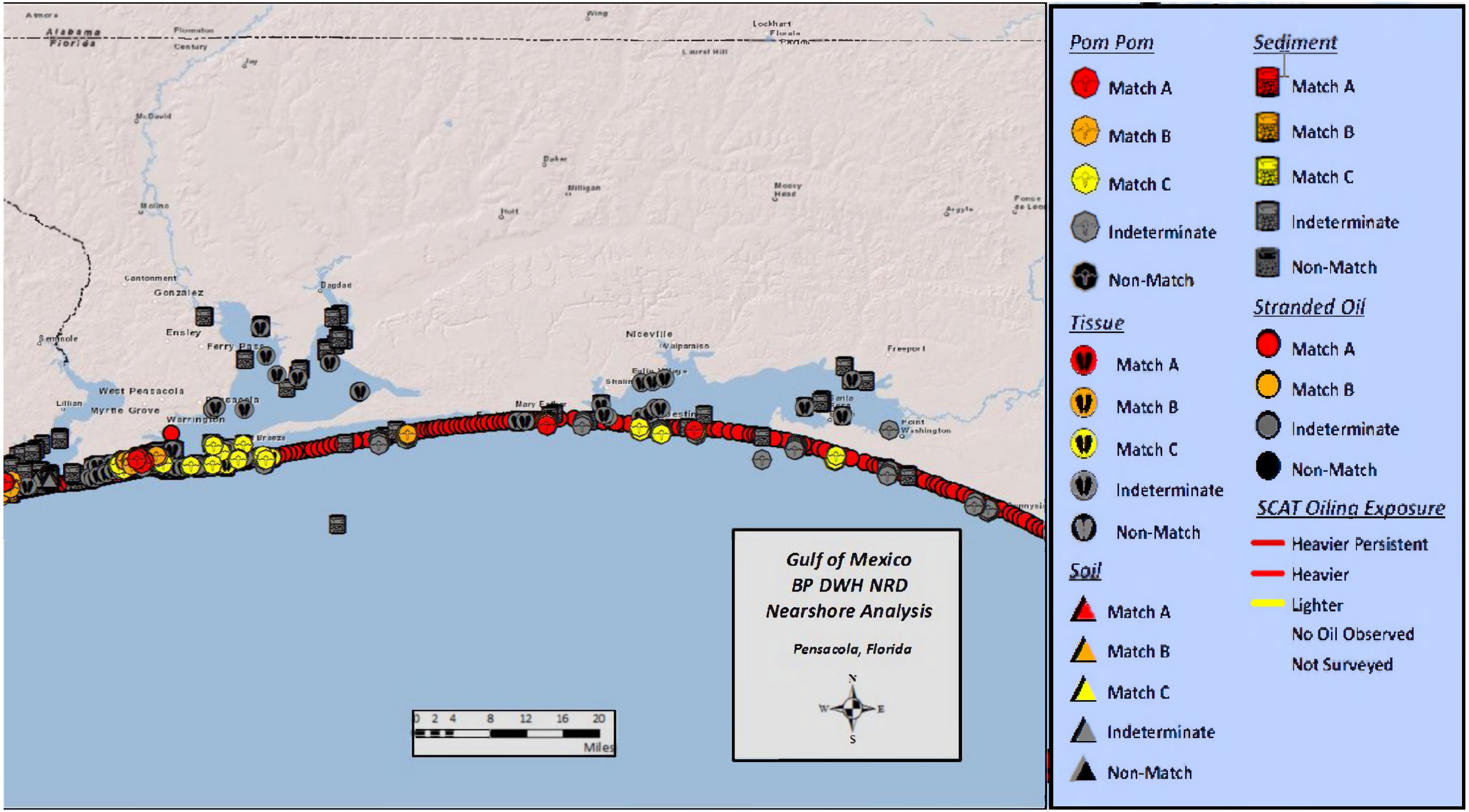

Figure 10. Nearshore Samples Collected in Pensacola, Florida.

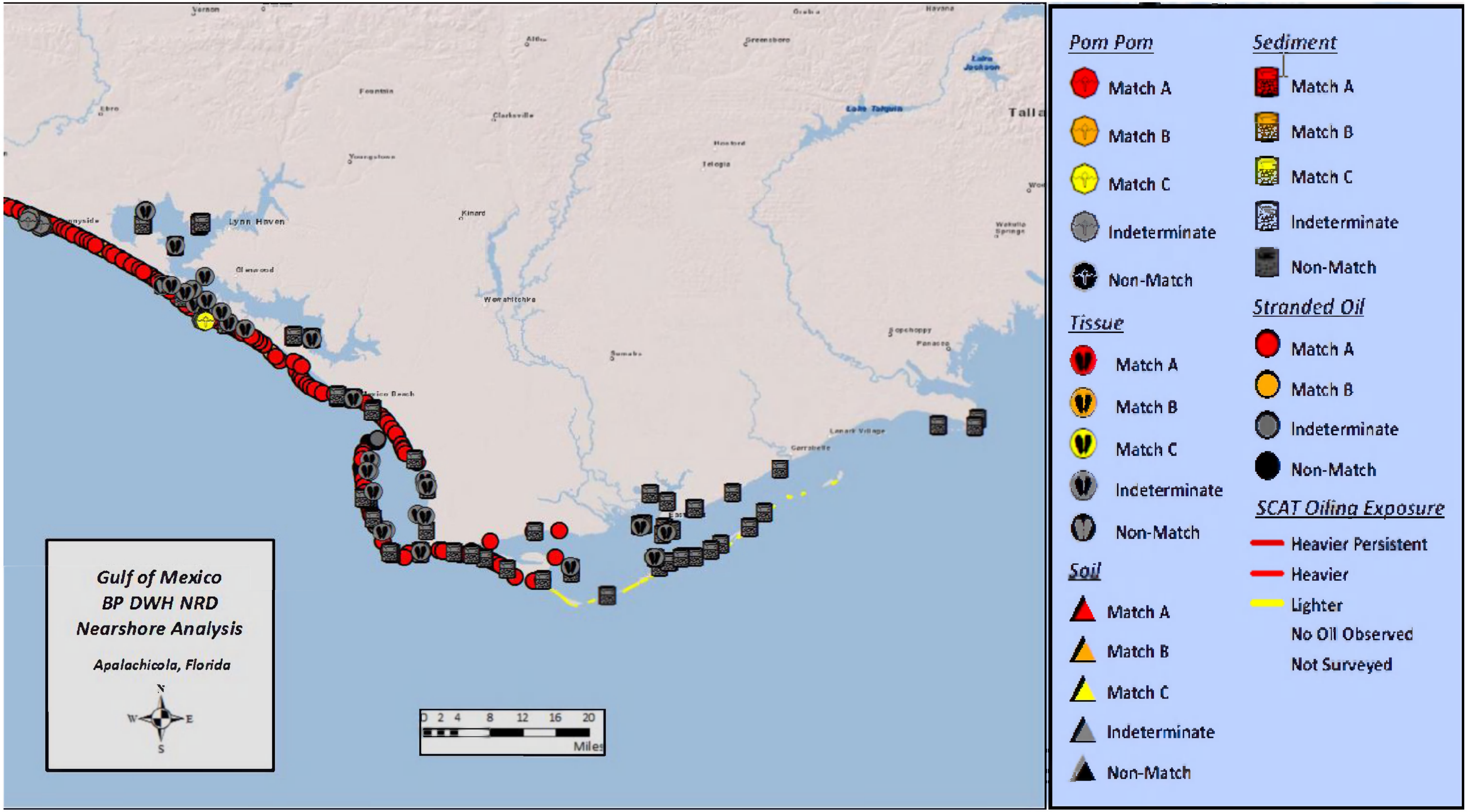

Figure 11. Nearshore Samples Collected in Apalachicola, Florida.

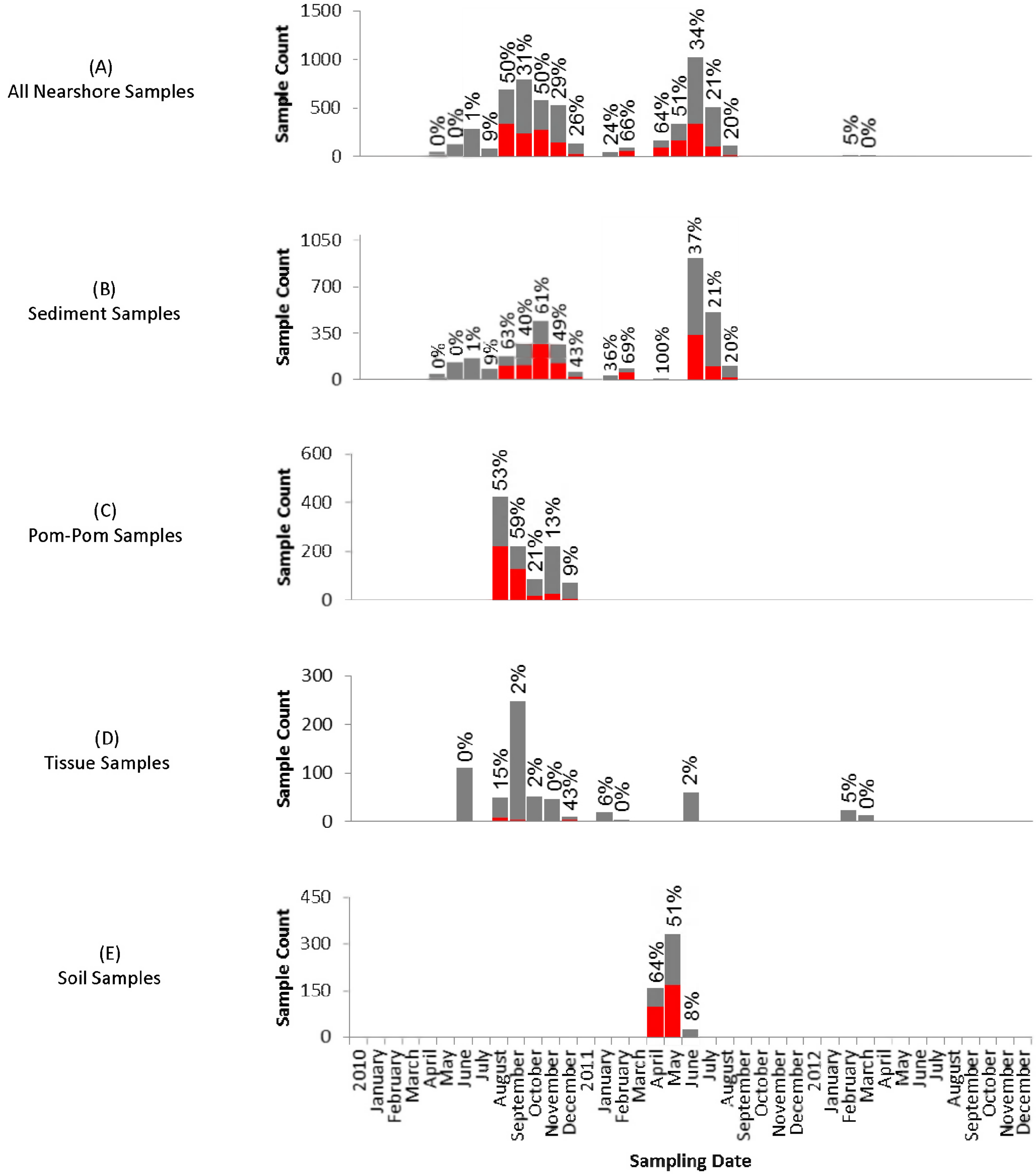

Figure 12. Chronology of Nearshore Sample Collection and Classification Code Frequencies: Red bars signify samples with Codes A, B, or C and grey bars signify Codes D and E.

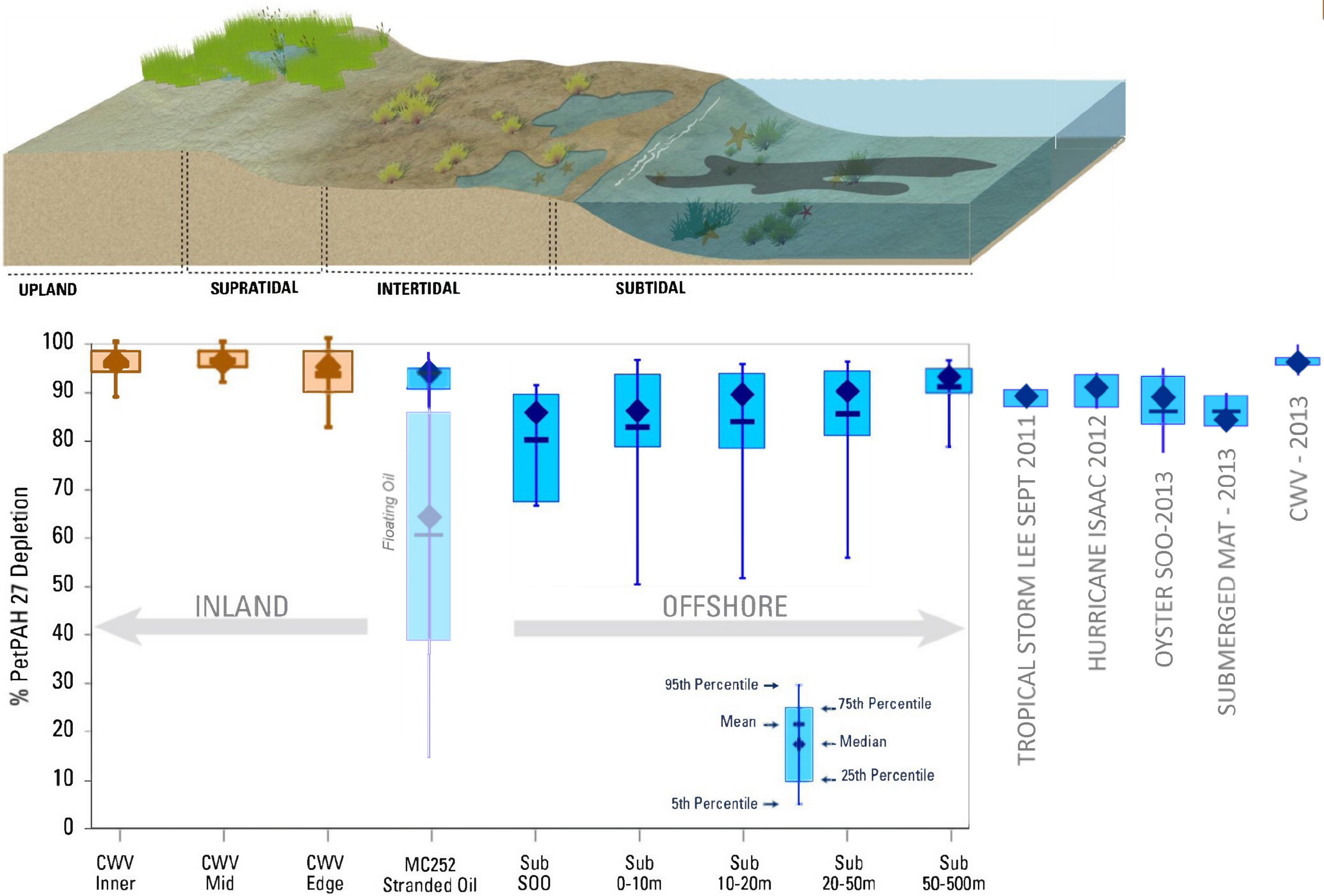

Figure 13. PetPAH27 Depletion Trends.

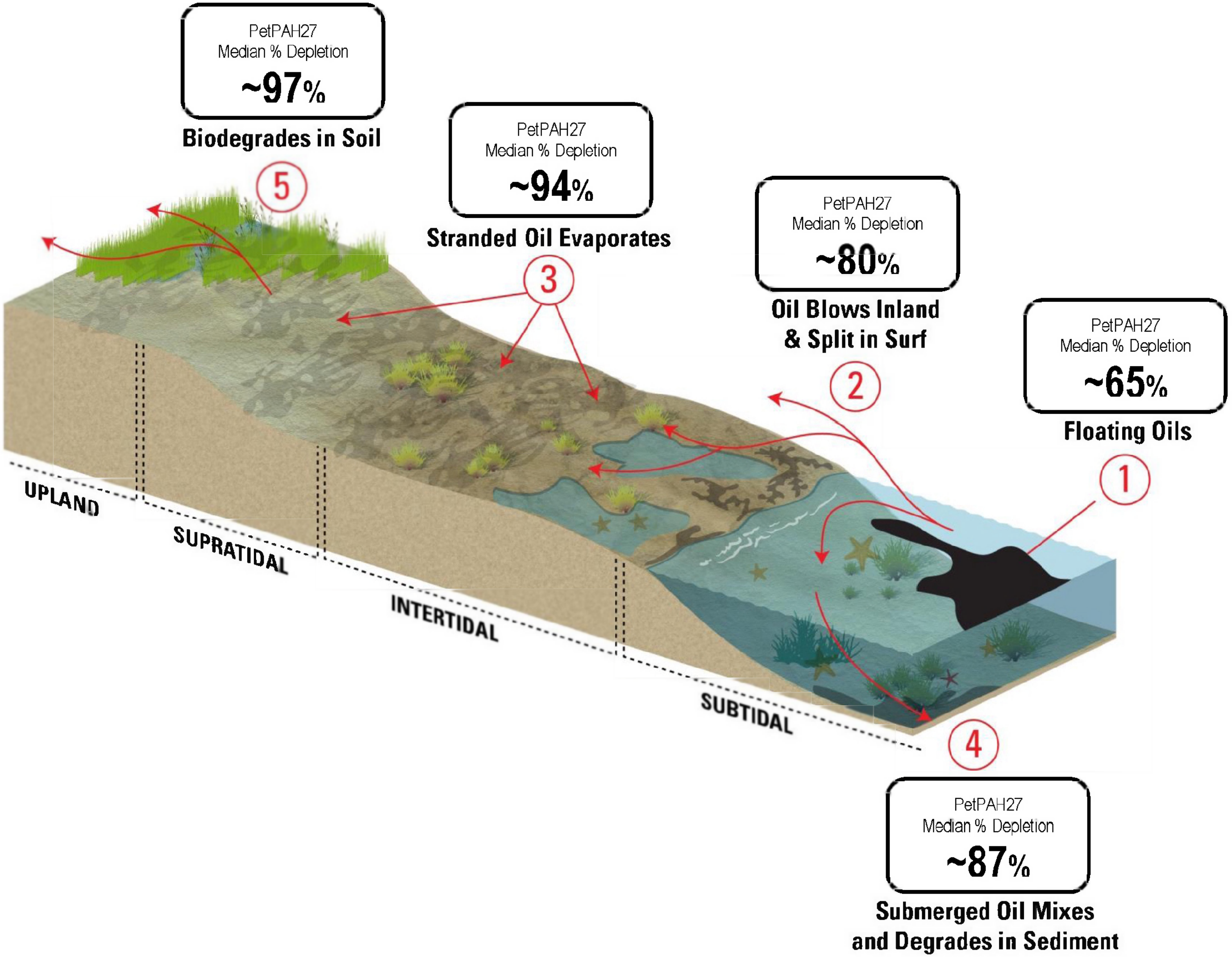

Figure 14. Nearshore Conceptual Site Model.